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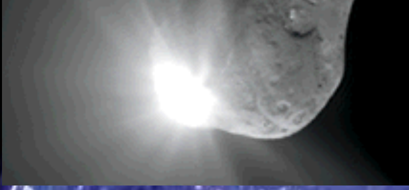

DEEP IMPACT: latest news p. 72

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October 2005

Astronomy®

Observing, telescopes, origin and fate of the cosmos

SPECIAL COSMOLOGY ISSUE

Why you live in multiple universes

Cosmic inflation and string theory suggest there's much more to the cosmos than what we see

FRONTIERS OF THEORY

The accident that saved the Big Bang

The return of cosmic strings

What makes a black hole tick?

Go inside the Andromeda Galaxy

Multiple universes, separated like bubbles, may populate the cosmos, our universe being only one among many. PAGE 34

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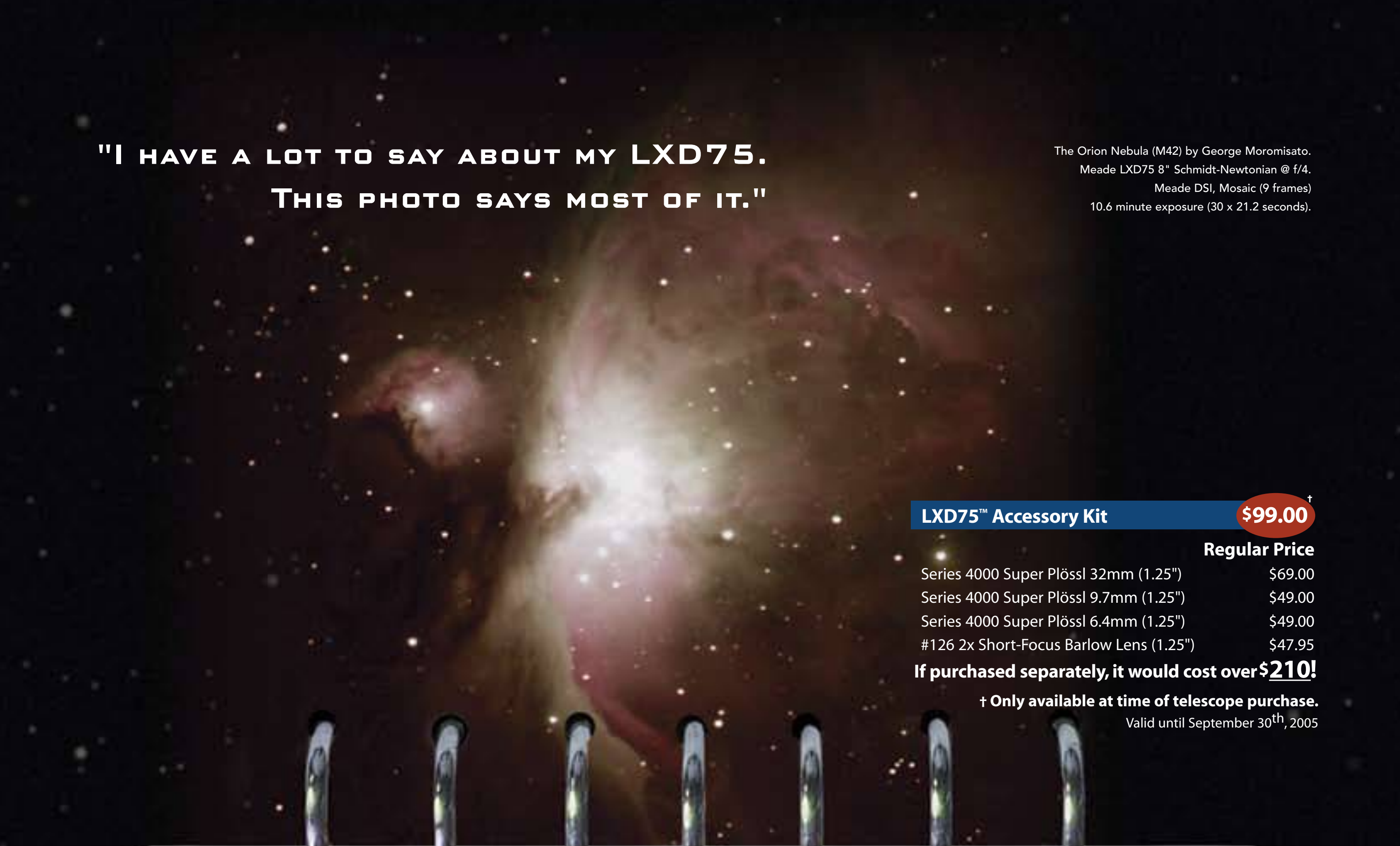
Vol. 33 • Issue 10



"I HAVE A LOT TO SAY ABOUT MY LXD75.
THIS PHOTO SAYS MOST OF IT."

The Orion Nebula (M42) by George Moromisato.
Meade LXD75 8" Schmidt-Newtonian @ f/4.
Meade DSI, Mosaic (9 frames)
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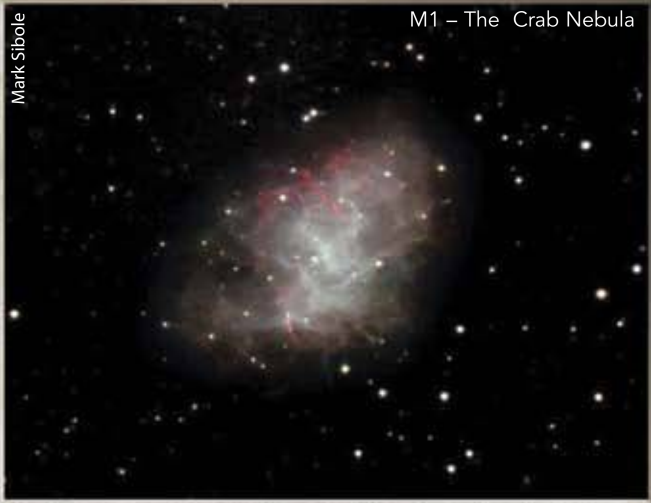
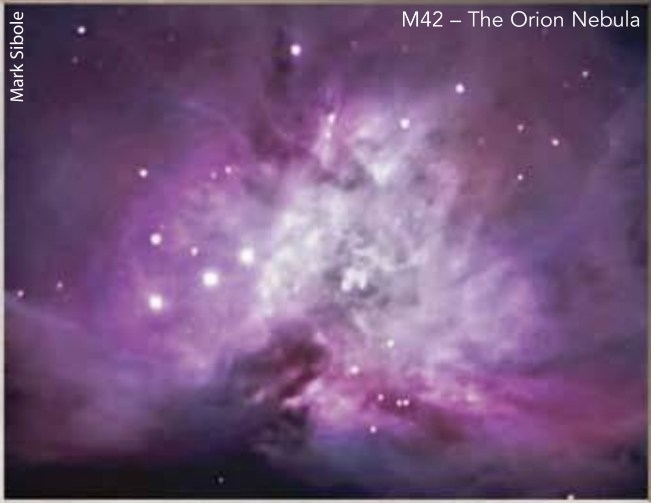


M1 – The Crab Nebula

Meade LX200 10" Schmidt-Cassegrain @ f/6.3, 20 frames x 30 seconds.



M42 – The Orion Nebula

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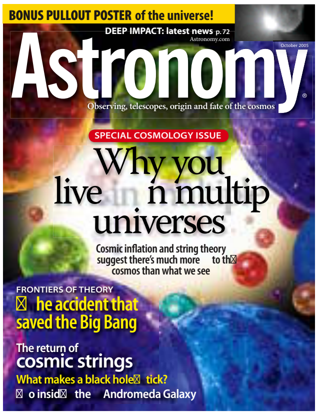
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DON DIXON

ON THE COVER

If some theorists are right, multiple unive sus pw ped into existence like champagne bubbles during the early period cosmologists call "inflation." As Steve Nadis reports on page 34, some of these universes could lack stars, others would disappear immediately, and ours might be the only one able to harbor life.

OL. 3, NO. 10

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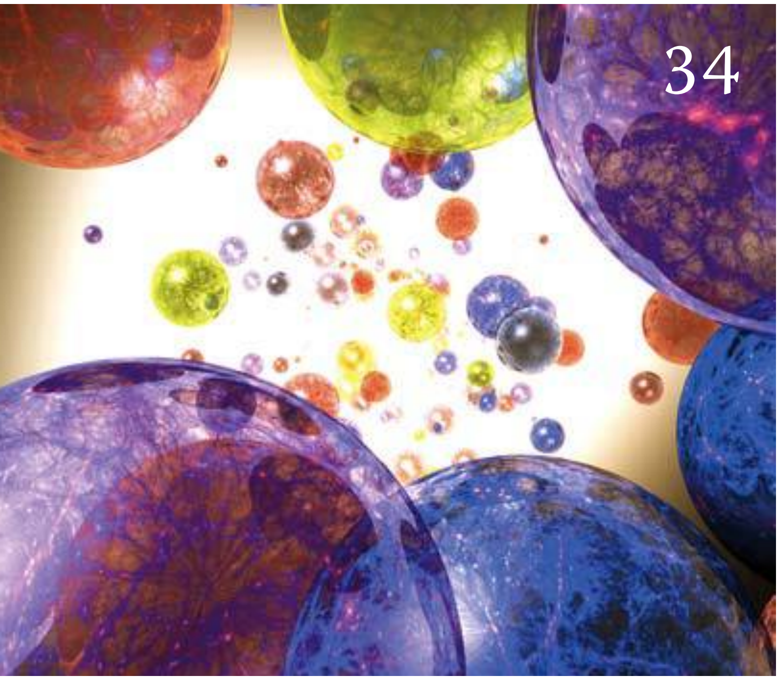
october 2005



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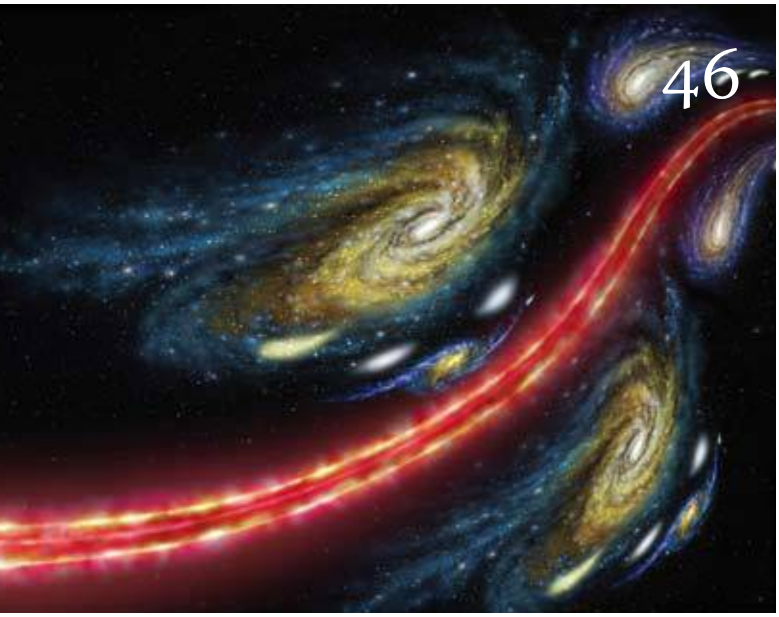

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Making multiverses

New tpists on old theories suggest our universe may be one of man that ex'st**STEVE NADIS**

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While adjusting an ant nna, wo astrqvdm rs mrde one of the greatest niscove ies Kf all tim**JAMES TREFIL**

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Long, thin, dense strands of primordial matter may wind their way through the universe. **STEVE NADIS**

ONLINE EXTRA: Watch cosmic strings interacb in the early universe.

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Get a sneak peak at NASA's new spacecraft that will probe the nature of dark energy, black holes, and gravity waves.

ANNE KINNEY, NICHOLAS WHITE, AND CHRISTOPHER WANJEK

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Eclipses span the globe

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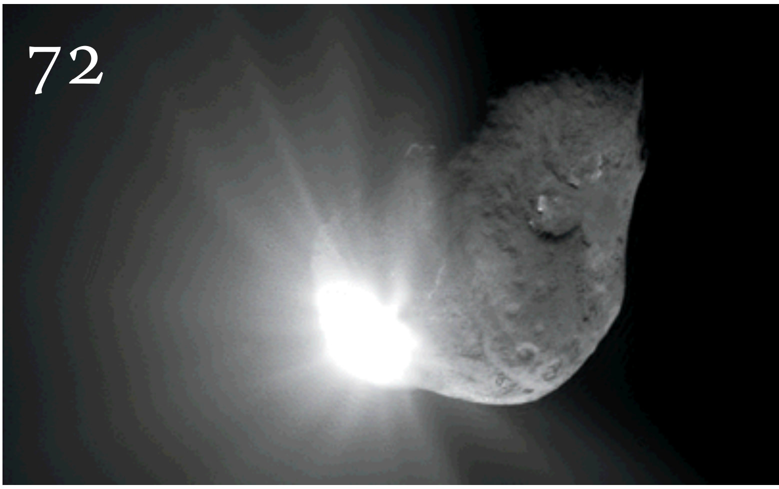
Deep Impact's mission went off without a hitch, as it slammed into a comet's nucleus. **RICHARD TALCOTT**



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See inside a black hole like never before. **RICHARD TALCOTT**

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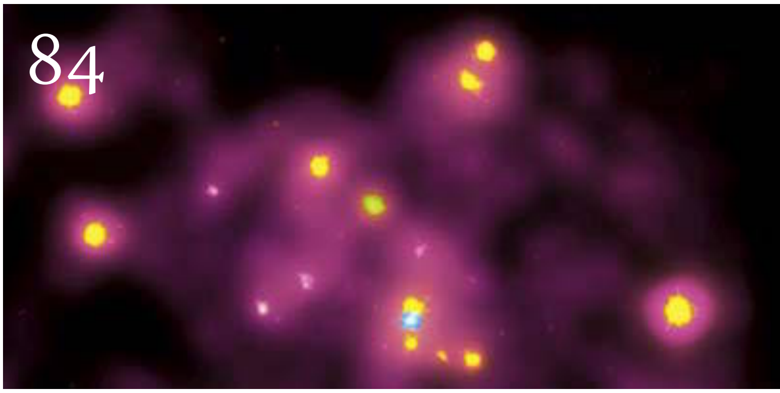
The Andromeda Galaxy offers a rich history of discovery, folklore, and science. **RAYMOND SHUBINSKI**



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Few astronomical topics are as confusing as star names. How did we get into this mess? **MICHAEL COVINGTON**

ONLINE EXTRA: Discover how celestial objects are named today.

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Observe the stars and preserve your yard's aesthetics with this clever design. **KENNETH D. WHEAT**

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A permanent observing site lets this astroimager pursue his celestial quarry quickly and easily. **GEORGE GREANEY**

GEORGE GREANEY

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BY DAVID J. EICHER

The cosmology special issue

Cosmology makes us think like nothing else. How was the universe born? Did galaxies, stars, or black holes come first? How have galaxies evolved during the past 10 billion years? What will be the cosmos' ultimate fate? Each of these questions, and many more, receives attention in this

special issue. Five science articles examine the latest and greatest ideas in cosmology.

In "Making multiverses" (page 34), Contributing Editor Steve Nadis eloquently explains why many cosmologists now believe our universe is one of many.

This gives us the term *multiverse* — the huge everything that contains "distinct, exponentially large regions with wildly divergent features." Nadis describes how astronomers use cosmic inflation, string theory, and the cosmological constant as evidence that our universe is just one part within a larger whole that we cannot see — and never will.

Physicist James Trefil describes the amazing discovery of the cosmic microwave background by Arno Penzias and Robert Wilson in "The accident that saved the Big Bang" (page 40).

While adjusting their Bell Laboratories antenna in the 1960s, Penzias and Wilson discovered cosmic static. This led to the confirmation of the Big Bang and the death of the competing steady-state theory of the universe's origin. More recently, evidence gathered by the COBE and WMAP satellites has added fuel to the Big Bang fire.

Nadis strikes again with "The return of cosmic strings" (page 46). Although a few years ago researchers had written off these long, exceedingly thin strands of matter, they are now back in vogue.

The last few years have seen growing acceptance of string theory: Physicist Edward Witten of Princeton University today says, "Strings of different sizes and kinds probably exist." Two decades ago, he argued strongly against their existence. If strings do exist, they hold the key to myriad explanations of the universe.

Space missions have always been at the forefront of cosmology. NASA now plans an ambitious program to solve three questions raised by Albert Einstein's theories: What powered the Big Bang? What happens at the edge of a black hole? What is dark energy?

In "Beyond Einstein" (page 52), astronomers Anne Kinney, Nicholas White, and Christopher Wanjek describe how the LISA and Constellation-X missions will tackle these questions.

As a treat for black-hole enthusiasts, check out "What makes a black hole tick?" by Senior Editor Richard Talcott (page 80). The clear explanation, together with a stunning illustration by A olf Schaller, is unlike anything previously produced.

And enjoy our bonus, foldout poster, "Cosmic vista," created by Princeton astronomers J. Richard Gott and Mario Jurić and coordinated by Associate Editor Frank Reddy. You'll want to hang on to this amazing map for future reference. It shows major features of the universe from Earth to the edge of the cosmos. A fitting addition to this special cosmology issue.

Yours truly,

David J. Eicher
Editor

Astronomy
Volume 33, Number 10

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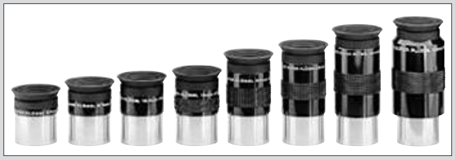

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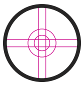

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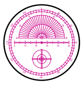

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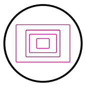

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Tack-sharp! Great alternative to Naglers. The 41mm and 24mm models deliver largest true fields in their barrel sizes. 24mm and 19mm stunning with Bino Vue.

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LUMICON The World's Best Filters & Astronomical Accessories

Lumicon International offers the best and most extensive line of astronomical filters in the world. Filters for every imagined visual and astrophotographic application, in many configurations and sizes. Filters for light polluted skies, planets, deep sky objects, galaxies, nebulae, planetary nebulae, comets, and solar prominences. All Deep Sky, UHC, OIII, H-Beta, and Comet Filters are individually tested and proudly inscribed with the percentage of light transmittance of their primary emission lines. Lumicon also offers a complete line of unique accessories, including the World Famous Easy Guider Series, Sky Vector Systems, Diagonals, Finderscopes, and Binocular Viewers. To ensure that Lumicon Products remain the World's Best, the strictest quality control standards are employed throughout the production process. All Lumicon Products are made to the highest standards available and come with a 100% Satisfaction Guarantee - Please Visit www.lumicon.com for Details.

DEEP SKY FILTERS The best light pollution filter on the market today. Blocks all high & low pressure mercury and sodium vapor lamp light, neon lights and airglow, while transmitting the rest of the visible spectrum. Excellent for both visual and photographic applications. Visually, the Deep Sky Filter is most useful under light-polluted skies, from where it reveals faint objects like star clusters, galaxies, nebulae and comets by darkening the background of space. Photographically, the Deep Sky Filter enables deep space photos to be taken through city lights and blocks natural airglow at dark-sky sites, thus improving results in film and CCD astrophotography.

1.25" – $99.95 • 1.25" Questar – $99.95
2" – $199.95 • Cassegrain Rear Cell – $199.95

ULTRA HIGH CONTRAST FILTERS The ULTIMATE nebula filter. The original LUMICON Ultra High Contrast Filter is unbeatable for revealing nebulosity. This achievement in filter performance is attributed to exclusively designed coatings that isolate the two doubly ionized oxygen lines (496 and 501nm) and the H-beta line (486nm) emitted by planetary and most emission nebulae. The result is superb views of the Orion, Lagoon, Swan and other extended nebulae. Useful to great advantage under dark skies.

1.25" – $99.95 • 1.25" Questar – $99.95
2" – $199.95 • Cassegrain Rear Cell – $199.95

OXYGEN III FILTERS The legendary LUMICON OIII narrow band-pass filter isolates just the two doubly ionized oxygen lines (496 and 501nm lines) emitted by diffuse, planetary and extremely faint nebulae. Thus, these faint objects become much more visible against the blackened background of space. The LUMICON Oxygen III Filter produces near-photographic views of the Veil, Ring, Dumbbell and Orion nebula, among many other objects. Performs best under both light-polluted and dark skies. You will be amazed at what the OIII filter allows you to see!

1.25" – $99.95 • 1.25" Questar – $99.95
2" – $199.95 • Cassegrain Rear Cell – $199.95

HYDROGEN-BETA FILTERS The Horsehead Nebula filter. The LUMICON H-Beta Filter isolates only the hydrogen-beta line of the spectrum (486nm) in a narrow pass-band just 9 nm wide. The result is extreme contrast between the black background of space and the delicate Hydrogen - Beta emission of extended nebulae. Now you can view extremely faint, special objects such as the Horsehead, Cocoon and California Nebulae. In many cases, the LUMICON H-Beta Filter is the ONLY way to view these objects. A transparent sky, a 8" or larger telescope, and the LUMICON H-Beta Filter, will tremendously aid in viewing those "notch in the belt" objects.

1.25" – $99.95 • 1.25" Questar – $99.95
2" – $199.95 • Cassegrain Rear Cell – $199.95

COMET FILTERS The LUMICON Comet Filter, a narrow bandpass system (25nm), isolates the 501nm OIII line and both Cyanogen lines at 511nm and 514nm. The high contrast gain of the filter reveals the delicate ionized tail of gaseous comets, allowing you to see their full extent. The Comet Filter also helps you to better distinguish gaseous comets from dusty comets which normally show little contrast gain.

Howard Brewington, famed comet discoverer, says: "I discovered Comet Aarseth-Brewington, 1989a1, using the LUMICON Comet Filter. The filter doubled the contrast, making the comet very easy to spot." Why make comet-hunting harder than it needs to be?

1.25" – $99.95 • 1.25" Questar – $99.95
2" – $199.95 • Cassegrain Rear Cell – $199.95

NIGHT-SKY HYDROGEN-ALPHA FILTERS Not intended for solar observing, the LUMICON Night-Sky H-Alpha Filter is a powerful photographic aid in overcoming light pollution during deep-sky photography. It will greatly reduce light pollution, making it ideal for photography of faint emission nebulae. Exposures may be increased up to 10 times without diminishing the black background in your photograph, thus, achieving strikingly improved results in black & white film and CCD astrophotography. Both filter surfaces have high light transmittance coatings for maximum performance.

2" – $69.95 • 58mm – $79.95 • 77mm – $89.95 • 82mm – $99.95

MINUS VIOLET FILTERS The LUMICON Minus Violet Filter greatly improves photographs taken through lens systems, producing pinpoint star images. It is especially recommended for all telephoto lenses. The Minus Violet filter passes the maximum amount of visible light, including the full blue, green, yellow and red portions of the spectrum. It absorbs violet and ultraviolet light below 420nm, thus eliminating blue halos around bright stars in color photography. In B&W photography it eliminates bloated and swollen star images caused by violet and ultraviolet light, which telephoto lenses cannot focus perfectly, due to chromatic aberration. This filter is unsurpassed in photographic performance.

2" – $69.95 • 58mm – $79.95 • 72mm – $89.95

LUNAR AND PLANETARY FILTERS LUMICON Lunar and Planetary filters are made from renowned Schott and Hoya optical glass. Each filter is individually precision ground and highly polished with ultra-high light transmittance coatings on both sides for ultimate contrast on lunar and planetary detail. Double stacking filters may also improve lunar imaging. Optimized for both visual and photographic applications. For a complete list of lunar and planetary filters and applications, please visit www.lumicon.com. 1.25" – $19.95 • 2" – $29.95

POLARIZING FILTERS LUMICON Polarizing Filters are manufactured from optically flat Hoya polarized glass. Performs best at cutting all glare and increases contrast on bright celestial objects such as the moon at full illumination, and can be double-stacked with other LUMICON filters for use on bright planets. They are also useful for daylight observation of land, sea and nature. In addition to polarizing the light, they reduce its intensity by a factor of about 3.

Also available in rotating polarized cell designs for variable levels of light transmittance to any value between 5% and 30%.

Single Polarizer 1.25" – $29.95 • 2" – $39.95
Variable Polarizer 1.25" – $39.95 • 2" – $49.95

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80mm Super Finder System Now Includes Custom Fit Carrying Case!

80MM SUPER FINDER SYSTEM The highest quality finder system on the market today, the newly redesigned LUMICON 80mm Super Finder features exceptionally" sharp optics, high contrast views and easy to use functionality. The LUMICON 80mm Super Finder is designed to switch conveniently from straight through to right angle in seconds with supplied extension adapter. Includes a front barrel focuser for fast and precise focusing. In addition, the LUMICON 80mm Super Finder includes a correct image right angle diagonal for hassle free pointing in any direction.

The LUMICON 80mm Super Finder also doubles as a high quality rich field refractor, yielding superb views of the moon, planets, star clusters, bright galaxies as well as daytime images. Use it with the optional Image Visor and reduce glare while increasing contrast and resolution on lunar and terrestrial views.

Objective Lens: Fully Multi-Coated 80mm Achromatic Lens; Focal length: 300mm; Includes a quality 25mm Kellner Crosshair Eyepiece; Super Finder System Weight: 2.7 lbs. Body color available in Black or White.

80mm Super Finder System – **$299.95**
80mm Super Finder Body (Body Only) **$219.95**
Image Visor – **$24.95**
2X Fully Coated Barlow Lens – **$39.95**

MULTIPLE FILTER SELECTORS LUMICON Multiple Filter Selectors allow you to switch back and forth between filters without having to thread and unthread them from your eyepieces or diagonal. The nose-piece also has threads, so one filter, such as a neutral density or polarizing filter, can be "stacked" with the others. Leaving one of the slots open lets you compare views with and without your LUMICON filters. Made from solid aircraft aluminum.

1.25" Multiple Filter Selector Features: Fits Standard 1.25" Filters; 5 Filter Positions; 6oz Light Weight Construction; 5/8" Low Profile Design; Includes 1.25" Eyepiece Adapter and T-Thread Adapter. Price – **$129.95**

NEW 2" Multiple Filter Selector Features: Fits Standard 2" Filters; 4 Filter Positions; Light Baffles for Astrophotography; 8oz Light Weight Construction; 5/8" Low Profile Design; Includes 2" Eyepiece Adapter and Male Cassegrain Rear Cell Adapter. *Filters sold separately.*

***Introductory Price:* $169.95**

ADVANCED CLEANING KIT The very best cleaning kit ever offered. The LUMICON Advanced Cleaning Kit has everything you need to clean even the most delicate lenses and mirrors. Safe to use on all optical surfaces. Includes LUMICON Lens Cleaning Spray, LUMICON Multi Coated Optics Cleaning Fluid, LUMICON Lens Cleaning Tissue, Ultra Brush Dust Remover, Air Blower Blush, 100% Cotton Swabs, LUMICON Micro-Fiber Cleaning Cloth, "Blow Off" Compressed Air and a Hard Carrying Case.

***Introductory Price:* $39.95**

SOLAR PROMINENCE FILTER SYSTEM

The LUMICON Solar Prominence Filter System converts your existing telescope into a Hydrogen – Alpha solar telescope. Viewing the sun in Hydrogen – Alpha light allows for amazing images of solar prominences, solar flares, sun spots, bright filaments and other surface features. Simply use a standard camera T-Ring and SLR camera for full photographic capability. Safely observe and photograph the sun at high and low powers directly through your own telescope.

The LUMICON Solar Prominence Filter System includes three components: 1. The Energy Rejection Prefilter; blocks all harmful radiation before it enters your telescope. 2. The Off-Axis Mask; stops down your objective and holds the Energy Rejection Prefilter. 3. The SPF Body; extremely narrow-band (1.5 Angstrom) Hydrogen-Alpha filter, providing high contrast imaging of solar features. This portion of the filter slides into a 2" focuser or diagonal. Includes a T-Thread camera adapter and a 1.25" eyepiece adapter.

Solar Prominence Filter System for 7" / 8" Cassegrain – $779.95 • Meade 10" SCT – $789.95 • Celestron 11" SCT – $799.95 • Meade 12" SCT – $809.95 • Celestron 14" SCT – $819.95 • Meade 14" SCT – $819.95 • Meade 16" SCT – $899.95

Solar Prominence Filter Kit available for telescopes not listed here. The Off-Axis Mask is not included and can be fabricated by customer. Price - $699.95

For more information, visit www.lumicon.com

DIAGONALS

Enhanced Mirror Diagonals

With 96 - 97 percent light reflectivity, 1/10 wave precision polished optics and individually performed double pass collimation tests, the LUMICON Enhanced Diagonal is a must for a fast and significant upgrade from any standard prism diagonal. Includes standard filter threads for trouble-free changing of eyepieces and accessories while using filters. Made from solid aircraft aluminum.

1.25" Enhanced Diagonal - $99.95
2" Enhanced Diagonal - $189.95

LumiBrite Mirror Diagonals

With greater than 98 percent light reflectivity, 1/10 wave precision polished optics and individually performed double pass collimation tests, the LUMICON Lumi-Brite Diagonal maximizes the performance of your telescope for ultimate contrast and resolution one can get from a star diagonal. The exceptional Dielectric Coating provides for a more durable and longer lasting surface. Additionally, objects appear much brighter, with truer color. Includes standard filter threads for trouble-free changing of eyepieces and accessories while using filters. Made from solid aircraft aluminum.

1.25" LumiBrite Diagonal – $149.95
2" LumiBrite Diagonal – $239.95

Prism Diagonals

1.25" Multi-Coated Prism Diagonal – $49.95
1.25" 90° Correct Image Diagonal – $69.95

BINOVIEWER

The LUMICON BinoViewer allows you to comfortably use both eyes while looking through your telescope. The efficiently designed light beam splitter allows for minimum light loss and improved image contrast up to 40 percent. The LUMICON BinoViewer uses precision polished, Grade-A BK 7 crown glass with the highest contrast and color correction available. Its fully multi-coated optics and roof prism design provides for maximum light transmittance, freedom from ghosting images, and built in image correction. Installs in seconds into standard 1.25" focusers or diagonals. Eyepieces not included.

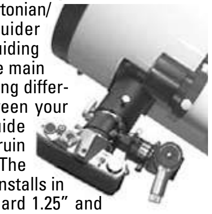
Specifications: Clear Aperture: 22mm; Focus Travel: 20mm; 1.25" Barrel, Threaded for Filters; Magnification: 1X; Overall Length: 120mm; Weight: 23 oz. Made in Germany.

Price – $799.95

EASY GUIDERS SYSTEMS

The most powerful astrophotographic accessory available today. LUMICON Easy Guiders feature patented radial and rotational off-axis adjustments, combined with a large off-axis pick off prism, selecting bright guide stars becomes a breeze for manual astrophotography or computer controlled auto-guiding.

Newtonian / Refractor Easy Guiders



The LUMICON Newtonian/Refractor Easy Guider allows off-axis guiding directly through the main telescope, preventing differential flexure between your telescope and guide scope, which can ruin your astrophotos. The low profile design installs in seconds into standard 1.25" and 2" focusers. Accommodates standard filters and camera T-Rings.

Newtonian/Refractor Easy Guider 1.25" – $189.95
2" – $189.95

Cassegrain Easy Guiders

The LUMICON Cassegrain Easy Guider allows off-axis guiding with your 5" – 9.25" cassegrain telescope. The included multi-coated 50mm focal reducing lens reduces the f-ratio from f/10 to f/6.5 or f/5, providing a wider field of view, increased edge flatness and shorter exposure times. The faster f-ratio combined with the ease of finding and guiding on bright stars, minimizes guiding error, making for successful astrophotos. Accommodates standard 2" filters and camera T-Rings.

Cassegrain Easy Guider for Celestron 5" – $249.95 • 7" - 9.25" – $249.95

Giant Easy Guiders

The LUMICON Giant Easy Guider is a very powerful photographic and visual tool. Utilizing a large multi-coated 80mm focal reducing lens, the f-ratio of your telescope is reduced from f/10 to f/6.5 or f/5, thus, increasing your field of view and edge flatness as well as decreasing exposure times. Unlike other focal reducing lenses, the LUMICON Giant Easy Guider has full frame illumination and pin-point star images on 35mm film, 120 format film and large format CCD cameras. Accommodates standard 2" filters and camera T-Rings. Meade 16" LX200 requires separate adapter.

Giant Easy Guider Meade 10" - 16" SCT – $399.95 • Celestron 11" - 14" SCT – $399.95

Easy Guider Accessories

Cassegrain Easy Guider SCT Accessory Adapter – $39.95 • Giant Easy Guider Adapter to Meade 16" LX200 – $169.95 • F/10 Viewing Adapter – $89.95 • SCT Accessory Adapter – $49.95 • Helicoid Focusable Off-Axis Tube – $79.95 • Giant Easy Guider Adapter Ring for Meade or Celestron – $49.95 • Newtonian/Refractor Easy Guider 2" Threaded Focal Reducer – $79.95

CAMERA T-RINGS

Canon, Canon EOS, Konica, Minolta, Minolta Maxxum, Nikon, Olympus, Pentax-K, Pentax-S – $19.95

EYEPIECES AND ILLUMINATORS

25mm Fully Multi-Coated Kellner Cross-hair Eyepiece – $69.95 • 12.5mm Orthoscopic Eyepiece with Illuminated Reticle – $149.95 • Pulseguide Illuminator – $49.95

CAMERA ADAPTERS

Prime Focus Camera Adapters: .965" – $19.95 • 1.25" – $24.95 • 2" – $49.95 • Eyepiece Projection Camera Adapters: .965" – $39.95 • 1.25" – $39.95 • 1.25" Eyepiece - T-thread Adapter – $29.95 • 2" – $49.95 • 2" Male Adapter w/ Filter Threads to Male T-Thread – $29.95 • Cassegrain Tele-Extender – $29.95

UNIVERSAL DIGI-CAM ADAPTER

The most versatile digital camera adapter available today. Attach any digital camera, with a standard 1/4" x 20 tripod thread, directly to your telescope or spotting scope. Includes fine motion controls for precise alignment. No tripods or brand specific T- Ring necessary. Made from solid aircraft aluminum.

Price: $39.95

DELUXE PIGGYBACK MOUNTS

The LUMICON Deluxe Piggyback Mount allows you to mount cameras or small telescope having 1/4" x 20 threads, onto medium and large telescopes. The LUMICON Deluxe Piggyback Mount is adjustable in altitude and azimuth, thus allowing you to align your camera with the optics of your main telescope. Four radii available for closest fit to your telescope tube.

Deluxe Piggyback Mount 6" – $59.95
Deluxe Piggyback Mount 8" – $59.95
Deluxe Piggyback Mount 10" - 12" – $59.95
Deluxe Piggyback Mount 14" – $59.95

RICH-FIELD VIEWERS

Cassegrain Rich-Field Viewers

The LUMICON Rich-Field Viewer takes your cassegrain's f/10 optics and reduces it to f/6.3 for beautiful low power, wide-angle views. Its multi-coated reducing lens has a large clear aperture, less coma than higher priced focal reducers on the market, while providing superb unvignetted views. Accommodates 2" diagonals and accessories.

Cassegrain Rich-Field Viewer for 5"-9.25" – $99.95

Giant Rich-Field Viewers

The same high quality 80mm multi-coated optical system and fine machining of LUMICON's famous Giant Easy Guiders are incorporated into LUMICON's Giant Rich-Field Viewer. Converting your cassegrain's f-ratio from f/10 to f/6.5 or f/5 provides for the maximum brightness and field of view your telescope allows. Ultimately, this feature will allow for the widest possible views of large galaxies like the Andromeda Galaxy, the Triangulum Galaxy, NGC 253, and pairs of galaxies like M81and M82. Accommodates 2" diagonals and accessories. Meade 16" LX200 requires separate adapter.

Giant Rich-Field Viewer Meade 10"-16" SCT – $279.95 • Celestron 11"-14" SCT – $279.95

SKY VECTOR SYSTEMS

The LUMICON Sky Vector System is a state-of-the-art digital setting circle system, providing virtually any astronomical telescope, whether equatorial or alt-azimuth, with a continuous, real-time digital readout of right ascension and declination coordinates. With the LUMICON Sky Vector, you will be able to find objects even faster than with most fully computer-driven telescopes. Its alphanumeric display uses a simple, easy-to-read scrolling text format. There is no need to polar align or to enter Latitude, Longitude, Date, Altitude, and Sidereal time – just initialize on one or two stars and you're ready to go! Includes Mounting Hardware.

Sky Vector 1 - The LUMICON Sky Vector 1 features: One or two star initialization; 4000-step encoders for high-resolution accuracy (0.09 deg.); Digital Right Ascension coordinate readout to 1 minute; Digital Declination readout to 10 arc-minutes; Guide mode for guiding you to the selected object in current memory; Database containing over 220 of the showpiece objects in the sky, including the famed "Messier Catalog." Price – $349.95

NGC Sky Vector - The LUMICON NGC Sky Vector has all the features of the Sky Vector 1, plus a large 12,000 object database; higher resolution display modes; IDENTIFY mode; and current constellation and chart number displays - all on a 16-digit red LED display. It can also be integrated with a personal computer for display of celestial object coordinates. Price – $489.95

Sky Vector Mounting Hardware available for the following telescopes: Celestron C5+, Early Model C8, Celestar 8, Celestar 8 DLX, Ultima 9.25 / 8 / 11, C11, C14; Meade LX10, 2080, 2120; 8" – 17" Dobsonian. From $69.95

Mounting Hardware can be fabricated by owner if telescope is not listed here. For more information, visit www.lumicon.com

SKY VECTOR ACCESSORIES

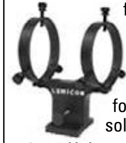
Sky Vector 1 Computer Kit – $269.95 • NGC Sky Vector Computer Kit – $419.95 • High Resolution 8192 Step Encoder Upgrade with Purchase – $29.95 • Version 3.68 Upgrade Chip for NGC Sky Vector – $59.95 • Serial Cable for NGC Sky Vector – $29.95

UNIVERSAL LASER POINTER BRACKET

The best selling LUMICON Universal Laser Pointer Bracket is designed to work with most popular red and green laser pointers. Easily attaches to your telescope with supplied mounting hardware. Now you can accurately point your telescope to the stars without sacrificing comfort. Includes advanced safety features and engineered for a lifetime of use. Made from solid aircraft aluminum.

Price: $39.95

UNIVERSAL DOVETAIL FINDERSCOPE BRACKETS



The LUMICON Universal Dovetail Finderscope Bracket will securely hold your finderscope to your telescope. The dovetail design permits fast removal and reinstallation of your finderscope while maintaining the alignment to your telescope. Mounts on most telescope tubes, with adjustments for other tube designs. Made from solid aircraft aluminum.

50mm Universal Dovetail Finderscope Bracket – $49.95 • 80mm Universal Dovetail Finderscope Bracket – $59.95 • Universal Dovetail Bracket Spare Base – $14.95 • Universal Dovetail Bracket Tripod Mounting Base – $19.95

ELLIPTICAL SECONDARY MIRRORS

1.3" Enhanced Secondary Mirror – $69.95
1.8" Enhanced Secondary Mirror – $99.95
1.3" LumiBrite Secondary Mirror – $99.95
1.8" LumiBrite Secondary Mirror – $149.95

EXTENSION TUBES

1.25" Extension Tube 1" Long Thread-In – $19.95
1.25" Extension Tube 2" Long – $19.95
1.25" Extension Tube 4.5" Long – $29.95
2" Extension Tube 2" Long Thread-In – $24.95
2" Extension Tube 2" Long – $24.95
2" Extension Tube 3" Long – $24.95

REDUCERS AND ADAPTERS

1.25" - .965" Reducer – $24.95
2" - 1.25" Reducer – $24.95
.965" - 1.25" Adapter – $24.95
1.25" – 2" Adapter – $39.95
2" Accessory Adapter for Cassegrain – $39.95

ASTROPHOTOGRAPHY FILM:

Fuji G800 35mm Non-Hypered – $14.95
Fuji G800 35mm Hypered – $19.95
Kodak TP2415 35mm Non-Hypered – $14.95
Kodak TP2415 35mm Hypered – $19.95
Kodak TP6415 120 Non-Hypered – $19.95
Kodak TP6415 120 Hypered – $24.95
Kodak TP4415 4"x5" 25 Non-Hypered Sheets – $54.95

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Prices do not include shipping and handling or state taxes where applicable.

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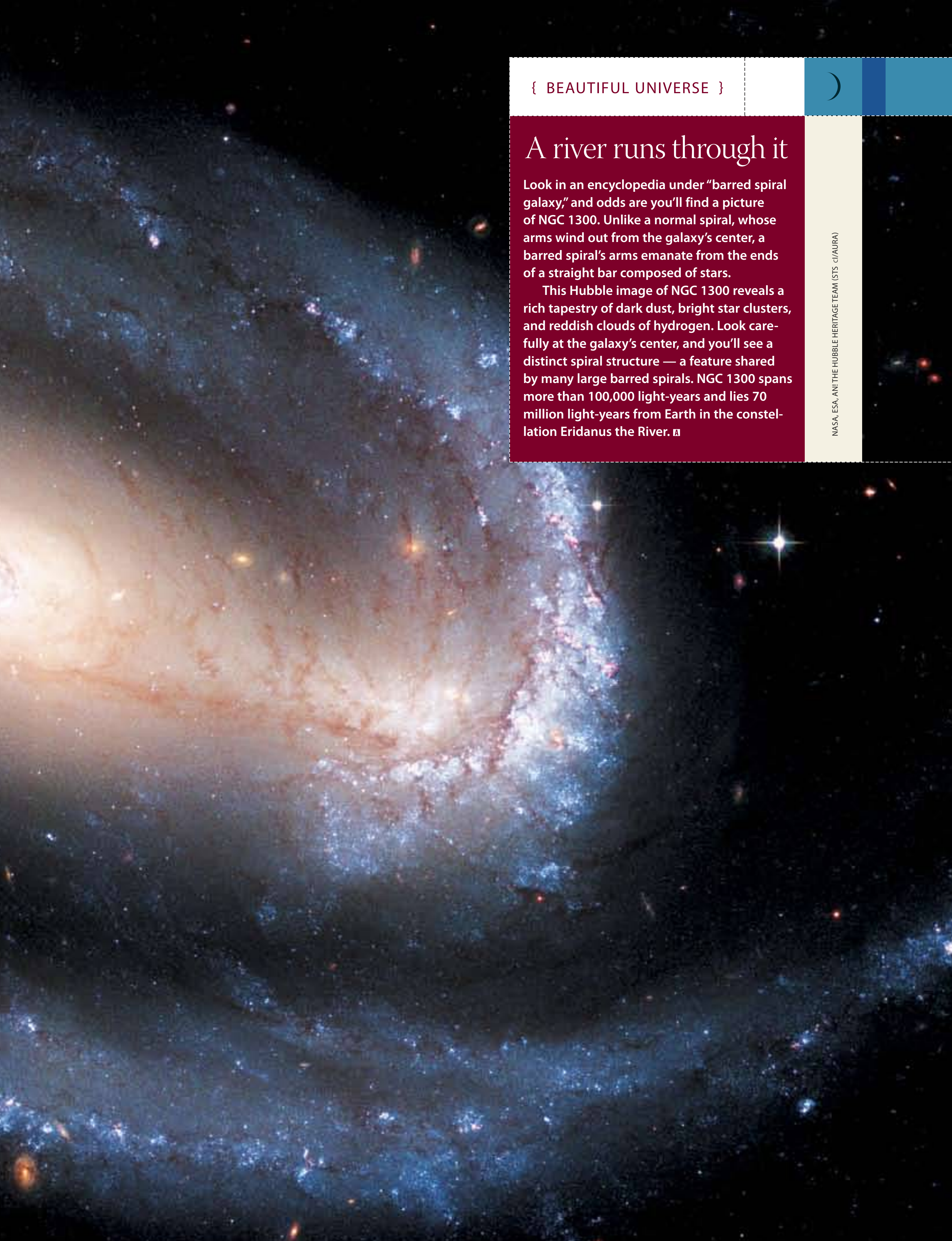
A river runs through it

Look in an encyclopedia under "barred spiral galaxy," and odds are you'll find a picture of NGC 1300. Unlike a normal spiral, whose arms wind out from the galaxy's center, a barred spiral's arms emanate from the ends of a straight bar composed of stars.

This Hubble image of NGC 1300 reveals a rich tapestry of dark dust, bright star clusters, and reddish clouds of hydrogen. Look carefully at the galaxy's center, and you'll see a distinct spiral structure — a feature shared by many large barred spirals. NGC 1300 spans more than 100,000 light-years and lies 70 million light-years from Earth in the constellation Eridanus the River.



NASA, ESA, AND THE HUBBLE HERITAGE TEAM (STScI/AURA)

Calm before the storm

Bruce Dorminey's "Dark threat" (July 2005) was thought-provoking. It's comforting to know our corner of the galaxy is quiet and peaceful. At least it will be until Gliese 710 pays the solar system a visit many years hence. ☾ Dorminey describes Gliese 710 as in Ophiuchus. It is, however, currently in neighboring Serpens Cauda, about 1° north of Eta (η) Serpentis. It should be a relatively easy target for small-telescope users who wish to get a glimpse of this future interloper. — **LOUIS MARCHESI,** LINCOLN, PENNSYLVANIA

BILL AND SALLY FLETCHER

COMETS MIGHT PUMMEL EARTH in 1.5 million years, when Gliese 710, a red dwarf, passes within 1 light-year of the Sun, disturbing some 2.5 million comets in the Oort Cloud.

Good recommendation

Thank you for Phil Harrington's quality article "Biaoculars under $100" (April 2005). I learned a lot and am very happy with the binoculars I ordered. — **DEAN HEPP,** MONTESANO, WASHINGTON

Space reservations

I'm confused by the decision not to return to the Hubble Space Telescope (HST) for one final servicing mission. Part of the advisory board's reasoning is that HST is already operating past its original design life. However, the same can be said of the remaining shuttles, which are 30 years old, and yet, they won't be retired for at least another 7 years. VentureStar, the only shuttle replacement idea ever developed — even partially — was scrapped after several billion dollars were spent on the project.

Moreover, if the shuttle must dock with the International Space Station (ISS) for every future mission, then we have reduced the most advanced machine ever built to something no more useful than a Soyuz rocket. That's a backward step 4 decades long. And still, no successors to either the shuttle or HST are on the way. — **FRANK LEBLANC,** DAYTONA BEACH, FLORIDA

Webcam wake-up

Damian A. Peach's "Small eyes on the sky" (May 2005) restored my faith in using inexpensive telescopes and cameras to capture great views of space objects. I currently use a Nikon Coolpix 2200 and a Meade refractor for capturing craters on the Moon with a filter, but now I will consider a webcam. — **CLARK MILLER,** WILMINGTON, DELAWARE

In the movies

Regarding Alister Ling's "Fireworks on the Fourth" (June 2005), I think it's ironic that in the movie *Deep Impact*, Earth was struck by a comet, and now, a spacecraft named Deep Impact strikes a comet.

This reminds me of another movie: It took us 65 million years to bring the dinosaurs back in *Jurassic Park*. Now, we get to avenge them by shooting at an interplanetary body. I can hardly wait for the sequel! — **ROGER SARGENT,** ALBION, PENNSYLVANIA

It's all relative

James Oberg says Earth rotates 360° in a day in the news story "The astronomy of launching a shuttle" (May 2005). A day is commonly construed to be 24 hours, but Earth rotates 360° in 23 hours 56 minutes and about 4.09 seconds. The story should have included a reference to rotation relative to ISS. — **RICHARD DAVEY,** EAGLE, IDAHO

Correction

To order the inflatable EarthBall, featured in "New products" (August 2005), contact the Orbis Company at: [t] 888.98.EARTH, [f] 360.376.6050, [e] didier@earthball.com. — ***ASTRONOMY* EDITORS**

We welcome your comments. Send letters to Astronomy *Letters, P. O. Box 1612, Waukesha, WI 53187; e-mail to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

PHILIP HALDEMAN
REDMOND, WASHINGTON

Send personal essays to *Astronomy* Forum, P. O. Box 1612, Waukesha, WI 53187; e-mail to mquandt@astronomy.com. Please include your name, city, state, and country. Submissions may be edited for space and clarity.

Maestro of the planets

A couple of summers ago, when I attended the Table Mountain Star Party near Ellensburg, Washington, I took note of a rule that discouraged playing recorded music during observing hours. Music, of course, establishes a mood, and one person's idea of an astronomical mood may be another's idea of annoyance. But I began to think about this from my point of view as a music critic, and I recalled how my early interest in astronomy crossed paths with a serious piece of music that is unique in its astronomical poignancy — and one that most of us have heard. I am speaking of Gustav Holst's *The Planets*.

Sir Adrian Boult's magical 1967 EMI recording and Zubin Mehta's later ones for Decca and then Teldec, often inspired me to haul out my trusty 6-inch reflector to aim heavenward.

But there is a puzzle, because knowledgeable listeners will point out — sometimes a bit haughtily — that when Holst was trying to decide how to characterize each planet musically, he took his motifs from astrology, not astronomy. Each "planet" in his massive seven-movement work — he leaves out Earth, and Pluto had not yet been discovered — bears an astrological association.

These mystical imprints were derived partly from a book in Holst's library called *What is a Horoscope and How is it Cast?* by Alan Leo. Holst took an interest in both astrology and eastern mysticism, but like any fine composer, he mainly wished his "Seven Orchestral Pieces" (as he titled his early sketches) to have complex emotional and psychological content that would function at the level of pure music.

Emotional variety is an obvious asset in large-scale orchestral compositions. So this led him to develop musical metaphors from Leo's book and give each planet human significance: "Mars: the Bringer of War," "Venus: the Bringer of Peace," "Mercury: the Winged Messenger," "Jupiter: the Bringer of Jollity," "Saturn: the Bringer of Old Age," "Uranus: the Magician," and "Neptune: the Mystic." The structure was that of an outward journey punctuated by psychological or philosophical states of mind.

Less than 2 decades before Holst wrote "Mars: the Bringer of War," his fellow Englishman H. G. Wells wrote of martians wreaking havoc in the suburbs of London in *War of the Worlds* (1898). Percival Lowell's observations of martian canals were being hotly debated. And by 1917, when *The Planets* was completed during a very real World War I, Max Planck and Niels Bohr had turned Einstein's universe into incomprehensible quantum weirdness.

FEW CAN SIT IN A dark room and hear the conclusion of *The Planets* without thinking of space's vastness.

Art, I think, often parallels science's broad trajectory. In *The Planets*, one senses something entirely of the scientific age. If "Venus: the Bringer of Peace" has beauty, it is cool beauty. If "Saturn: the Bringer of Old Age" has melancholy, it is timeless melancholy. The eerie finale, "Neptune," evokes the terrifying beauty of solitude, echoes mystical longings, and puts us in awe of the starry distances.

At its conclusion, the wordless, ethereal chorus fades so slowly that their sirens' call lingers only in the imagination. Time and space have no boundaries. Few can sit in a dark room and hear the conclusion of *The Planets* without thinking of space's vastness. The music will, indeed, "have its way."

Later in life, Holst gave up his belief in astrology, and the influence of eastern mysticism in his music waned. One of his later compositions, *Egdon Heath*, was emblematic of the change. This 13-minute tone poem — a piece of orchestral music played in one movement — was given a chilly reception at its premiere in 1928, while Holst came to believe it was his best work.

"It was stark and austere," said Holst's daughter, Imogen, "and free from the least breath of compromise. There were no clinging melodies to woo the ear, no satisfying harmonies to lull the senses into a pleasing security."

Holst died in 1934. He had spent most of his time as a music teacher at St. Paul's Girls' School in Hammersmith, England, composing at the school mostly on weekends and holidays, when everything was quiet and he had time to himself.

I imagine him in his large, silent room at the school, penning what I heard on those nights when his music augmented my interest in the night sky. Maybe the true measure of Holst's genius is contained in a question I was asked by a fellow observer at the star party on Table Mountain: "Is there anything else like *The Planets*?"

With a little self-conscious irony, I smiled. "No, I'm afraid not. Other composers seem quite deficient in that area."

Philip Haldeman *is a classical music critic for* American Record Guide.

{ BOB BERMAN'S STRANGE UNIVERSE }

BY BOB BERMAN

Ode to kerosene

Many of us heat our homes with oil, and right around now is when we buy some. I used wood for 13 years, believing the old saying that "wood heats you twice: once when you split it, again when you burn it." Well, they forgot to mention the third time, when it sears your hand when you touch the stove. Now, I heat with fuel oil, whose only down side is that it costs $963 a gallon. It's almost cheaper to create warmth by burning dollar bills.

Fuel oil is similar to kerosene, and some north-state and Canadian folks buy kerosene for the coldest months because it doesn't gel. The rest of us fondly remember kerosene for all the times we used it camping. A Coleman kerosene lamp delivers hours of brilliant light. It's easy to love.

These days, kerosene is what gets us around: It's the fuel used by big commercial planes. Jet fuel *is* kerosene. It's relatively cheap, and large jets need "cheap" because a 747's wings hold enough fuel to fill a swimming pool. You've probably already noticed that big airports offer the nostalgic smell of burning kerosene.

What does this have to do with outer space? Plenty. When America first blasted astronauts into suborbital flights inside claustrophobic Mercury capsules, the propellant those Redstone rockets used was, yep, plain old kerosene. It was the most popular rocket fuel of all, and still is. The idea was the brainchild of Russia's Konstantin Tsiolkovsky (1857–1935), who, exactly a century ago, wrote that kerosene was the way to reach the stars. American Robert Goddard agreed: On March 16, 1926, his groundbreaking kerosene and liquid oxygen rocket made history even though it went up only 41 feet.

Fast forward to the Apollo years, 1969 to 1972, and the wonderful Saturn rocket that got us to the Moon. It was named Saturn because the previous rocket had been called Jupiter, and they decided to continue the sequence. That brilliant public relations idea ended abruptly when they got to giggle-producing Uranus.

Anyway, the Saturn rocket's second and third stages used J-2 engines that burned hydrogen and oxygen, like today's space shuttle. Oxygen is a no-brainer because you need it to make fire in the first place, and it ignites hydrogen. This combination is wonderfully lightweight and packs the greatest wallop for its mass. Its intense blue-white flame appears to create smoke, but it's really steamy droplets of hot water, so it's even ecologically friendly. When Challenger blew up in 1986, all the white smoke that enveloped it was, simply, a cloud.

> When Challenger blew up in 1986, all the white smoke that enveloped it was, simply, a cloud.

We digress. It won't surprise you to learn the Saturn's incredible first-stage engines, each more powerful than any entire rocket ever built, used ordinary kerosene. "What?" you ask. "You mean smelly kerosene powered humans to the Moon?"

That's right. Lots of it. Each of the five colossal F-1 engines burned 3,000 pounds per second. Getting so much kerosene sprayed at once required a big fuel pump with an astonishing 65,000 horsepower. Imagine: Your car's entire engine probably is around 160 horsepower, and here's a mere fuel pump with 65,000. Wernher von Braun and his friends didn't screw around.

Well, I was going to dedicate this article to kerosene, because that liquid took us to the only celestial body on which humans have ever walked, or hopped. But worshipping kerosene is starting to sound stupid, so let's look at other fuels, too.

When near the Moon, Apollo used super-simple engines that burned hypergolic propellants. They require no ignition because the two chemicals, hydrazine and nitrogen tetraoxide, burst into flame all by themselves, immediately upon contact. If you absolutely need the motor to fire, and don't want to mess around with sparks or ignition systems, that's the way to go. They worked every time.

Right now, the space shuttle's hydrogen and oxygen are as clean and powerful as you can get, but we all know antimatter is much better. Once we get over the technological hurdle of manufacturing it (current worldwide annual production is only 1⁄100 of a microgram), it will rule supreme. Nothing else offers 100-percent efficiency, where a single gram provides one trillion trillion ergs of energy. Let a penny meet an antipenny — a quarter-ounce of mass — and it could power all the world's lightbulbs for 20 days.

Maybe someday our houses can use it, too. A feather's weight of antimatter would run a home for years. But manufacturers will have to be careful. If your thermostat sends a dot too much into the chamber, boom! There goes the whole neighborhood. Up to the Moon.

Maybe we should stick with kerosene.

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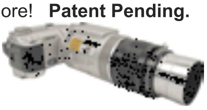

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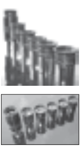

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BY GLENN CHAPLE

How to navigate the heavens

In each issue of *Astronomy*, you'll find an all-sky map — a circular chart that shows the appearance of the sky after sunset this month. The all-sky map — found on page 63 of this issue — can help beginners locate and identify major stars and constellations. As the directions note, you hold the all-sky map overhead and orient it so a direction label matches the direction you're facing. Do your arms tire easily? You also can hold the map in front of you, as if it were a car's steering wheel. Turn it so the direction label corresponding to whichever horizon you're facing is at the bottom.

But, perhaps you want to go outside before sunrise tomorrow, when the stars and constellations will be totally different from what's portrayed on the all-sky map. What then? You need a planisphere!

Like our all-sky chart, a planisphere portrays a full view of the night sky. It adjusts for any time and date of the year. It has two rotating parts — a star wheel and a horizon mask with an oval window. Align the date with the time you're observing, and the visible stars and constellations appear in the window. Now use it the same way you'd use our all-sky map.

A planisphere isn't just a beginner's toy. For more than 30 years, a planisphere has been my go-to tool for planning evening skygazing sessions. Early last April, I participated in a Messier marathon star party sponsored by the Amateur Telescope Makers of Boston. Early in the day, I consulted a planisphere to determine which constellations — and, therefore, Messier objects — would have set in the west by the time I planned to begin observing. This planning resulted in a more efficient marathon.

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A PLANISPHERE will show you exactly what's in the sky tonight. But don't forget your star atlas and the current issue of *Astronomy*. *ASTRONOMY*: JAMES FORBES

Where can you get a planisphere? Try the gift shop of your local planetarium or science museum, the science section of a bookstore, or any specialty shop that sells telescopes and binoculars.

You also can purchase one by mail or online through major suppliers of astronomical goods, like the companies that advertise in this magazine. Expect to pay between $10 and $15. One word of caution — be sure the planisphere you select is designed for your latitude.

If you're a "do-it-yourselfer" or a classroom teacher looking for a neat activity for your students, you'll find a free planisphere at www.washjeff.edu/physics/plan.html.

Enjoy a more detailed look

As useful as it is, a planisphere can't do it all. It can show you where to find Aquarius in tonight's sky, but not the location of the globular cluster Messier 2 in that constellation. Here's where a star atlas comes in.

A star atlas is a road map of the night sky. For the novice skygazer, I recommend the following atlases:

- *Norton's Star Atlas and Reference Handbook*, 20th edition by Ian Ridpath
  This classic star atlas, recently revised, has been around for nearly a century.
- *The Cambridge Star Atlas*, 3rd edition by Wil Tirion
  This atlas contains excellent sky charts, and lists of interesting sky objects.
- *The Edmund Mag 6 Star Atlas* by Terence Dickinson et al.
  Astronomy writer Terence Dickinson wrote the handbook portion of the *Mag 6 Star Atlas*, artist Victor Costanzo drew up the sky charts, and I supplied data tables on noteworthy objects plotted on each chart. Alright, so maybe I'm a bit prejudiced on this one.

Don't forget your magazine

Planispheres and star atlases have a common limitation — neither can portray the continually changing positions of solar system objects. Your monthly issue of *Astronomy* takes care of that!

Our "Sky this month" (page 60) provides easy-to-understand tips on what to see and where to see it in the night sky — from the Moon to deep-sky wonders. With your current issue of *Astronomy*, a planisphere, and a star atlas, you have the night sky covered!

Next month: Observing Mars with small telescopes, plus a return to the "Great Square." Clear skies. ▲

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{ PHIL HARRINGTON'S BINOCULAR UNIVERSE }

BY PHIL HARRINGTON

The Swan delights

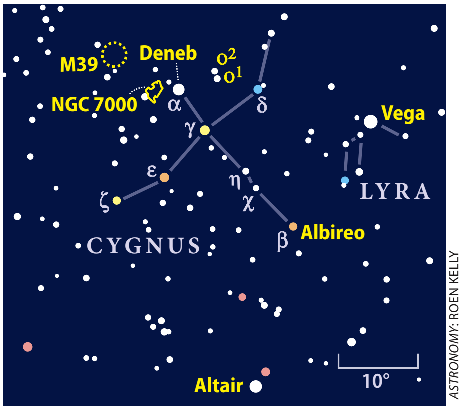
Although the nip in the air tells us fall is here, the Summer Triangle — Vega, Altair, and Deneb — still stands proudly above the western horizon this month. Of these, Deneb rides highest in the sky. The illustration on this page shows that Deneb marks the tail feathers of Cygnus the Swan. Everyone seems to be able to recognize the constellation **Cygnus** thanks to its prominent cross-like figure. In fact, this familiar shape led to Cygnus' nickname: the Northern Cross.

Although you'd never know from looking at it casually, **Deneb** is one of the most luminous stars in the entire sky. Even though it appears fainter than **Vega** and **Altair**, Deneb actually emits much more energy than either.

So, why is Deneb fainter? It's simply a matter of distance. Altair lies 17 light-years away. Vega is not much more distant at 25 light-years. Deneb, however, lies nearly 1,500 light-years away. Were it as close to us as Altair, Deneb would shine as brightly as the Quarter Moon. Wow!

Cygnus marks one of my favorite binocular playgrounds. Even from my moderately light-polluted suburban backyard, I can sit back on a chaise lounge, peer through my modest 10x50 binoculars, and trace the gentle glow of the Milky Way from Deneb southward to the star **Albireo**, which marks the bird's beak.

Small telescopes reveal Albireo's true identity as a showpiece double star with a 3rd-magnitude golden primary star accompanied by a 5th-magnitude sapphire-blue companion. Their colors don't show up as well, but both stars can be spotted through steadily held 10x50 binoculars.



ASTRONOMY: ROEN KELLY

USE THIS FINDER CHART to locate objects in and near Cygnus. Remember to be patient, and hold your binoculars steady.

If double stars interest you, then stop by **Omicron (ο) Cygni**, one of the sky's finest objects through binoculars. Look for it 5° — or about two-thirds of a binocular field — northwest of Deneb. The Omicron system is another colorful pair, with a 4th-magnitude orange star accompanied by a 5th-magnitude bluish sun. Their colors stand out even in their rich neighborhood.

Put your skills to the test

Up for a couple of challenges? Good. Let's begin with the open star cluster **M39** (NGC 7092), found along the lane of the Milky Way about 9°, or approximately 1.5 binocular fields, northeast of Deneb.

To find it, scan from Deneb to a small arrowhead of stars just to the northeast. Follow the arrowhead's aim to a string of six faint stars that continues to the east-northeast. M39 lies to the east of the sixth (easternmost) star in that line. Through most binoculars, M39 will look like a tiny, triangular grouping of about two-dozen faint points. Whenever I am fortunate enough to view from a dark location, M39 appears suspended in front of a blanket of faint stardust.

Let's finish with the **North America Nebula** (NGC 7000). Although spotting this celestial continent is tough, it is actually easier to see through binoculars, or even with the naked eye, than through the narrow fields of most telescopes. Still, you'll need dark, perfectly clear skies, a steady hand, and sharp eyes to make it out. Take aim at Deneb, and then look about 3°, or half a binocular field, to its east.

No luck? Here's a hint. Look for the "East Coast," from the Carolinas to Florida and the Gulf of Mexico. These are the easiest parts of the nebula to see thanks to the darkness of the "Atlantic Ocean" formed by a separate dark nebula silhouetted in the foreground. The "West Coast" is much more difficult to distinguish.

Even though the North America Nebula photographs beautifully, we can never see its distinctive red color no matter how hard we try. Our eyes' color blindness in dim light reduces it to a faint grayish glow.

How to hold binoculars

Tom Strobel, from White Bear Township, Minnesota, asks how to hold binoculars steadily. Grasp the barrels around the objective lenses, cradling them with your forefingers and thumbs. This seems to work best, although I prefer putting binoculars on a tall photographic tripod or, better still, a parallelogram mount. A separate support also makes it easier to go back and forth between binoculars and star maps.

Cygnus holds so many beautiful star fields, it's easy to spend the evening casually scanning the sky through binoculars. Next month, we'll pay a royal visit to the queen of the fall sky. Till then, remember: Two eyes are better than one. **A**

ONLINE EXTRA To find more of the Swan's hidden treasures, visit www.astronomy.com/toc

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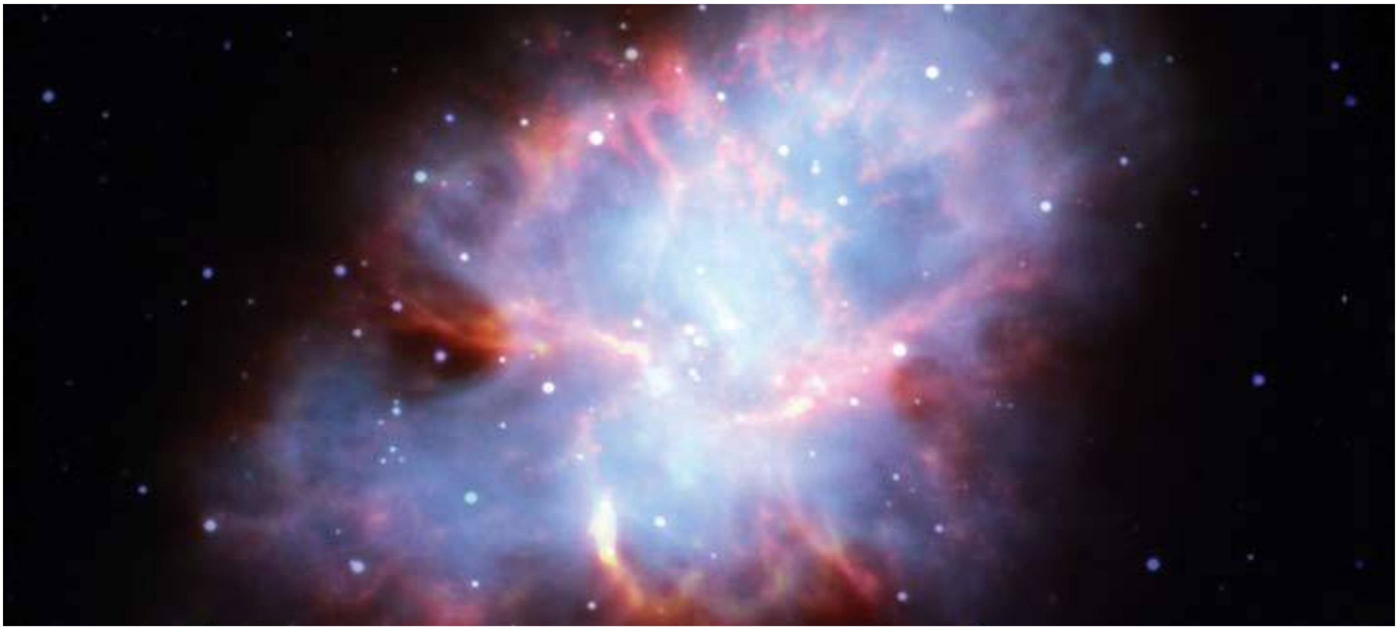
MAKING MOLECULES. In space, hydrogen is mostly molecular, with two atoms linked in a pair. The highly textured surfaces of interstellar dust grains attract hydrogen and make it easy for stray atoms to jostle and join into molecules.

news 10

Possible methane lake found on Titan, fight for that dark night, Opportunity rolls free, Cassini gets up-close and personal with a saturnian moon



NASA/JPL-CALTECH/T. TEMIM ET AL./NOAO/NSF/AURA

CLEAN REMNANT. The Crab supernova created no fine, cool dust, and seems to have vaporized dust its star made before the explosion.

26 **Sun flash helps prep ESA lunar orbiter**
27 **Tenth planet found**
28 **Stellar halos may hold clues to cosmic origin**
30 **Spririt gets up early and observes martian meteor**

Spitzer: Crab Nebula is "smoke-free"

Astronomers suspect exploding stars help make the universe a dustier place. But new Spitzer Space Telescope images show the Crab Nebula, the wreckage of a star that exploded in A.D. 1054, contains none of the fine, micron-wide, smoke-size dust particles expected to condense out of supernova ejecta. The team sees only dust particles 10 to 100 times this size.

"This is a real surprise," says Tea Temim, the University of Minnesota graduate student who led the study. She presented the images June 1 at the American Astronomical Society's summer meeting in Minneapolis.

"We know dust forms in supernovae," says Robert Gehrz, Temim's adviser and a collaborator on the study. "SN 1987A in the Large Magellanic Cloud formed dust about 600 days after the explosion." Elements like carbon, for example, should be among the first to condense and clump together. "Theoretically," Gehrz says, "we expect as much as a solar mass to form, but when we look with infrared instruments, we see very little."

It's difficult to distinguish newly formed dust in recent supernovae from dust produced by the star before it erupted. Here, too, the Crab Nebula seems cleaner than expected. The new images show no dust halo from the Crab's progenitor.

So, where did this smoke-size dust go? "I think shock waves from the explosion may have destroyed it," explains Gehrz. — **FRANCIS REDDY**

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HUBBLE'S MOUNTAIN. Mattias Mountain is the new director of the Space Telescope Science Institute in Baltimore, which runs science operations for NASA's Hubble Space Telescope and the planned James Webb Telescope.

Possible methane lake found on Titan

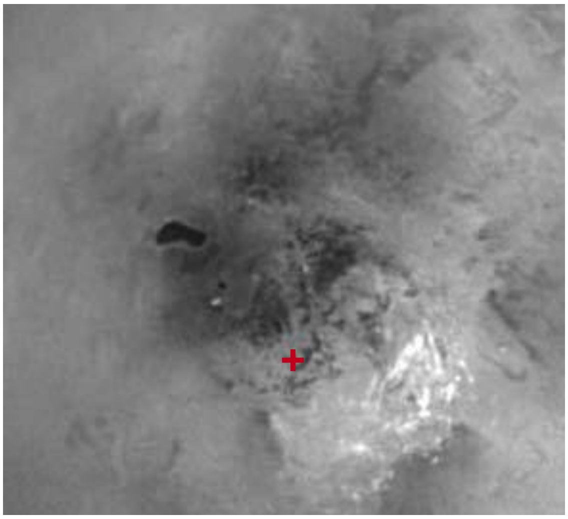
A dark spot on Titan with a footprint shape and a smooth, beach-like outline may be a methane lake, say Cassini mission scientists. Located close to the saturnian moon's south pole, the Lake Ontario-size feature lies in Titan's cloudiest region — where churning storms are common, and hydrocarbon rains are likely.

Cassini has imaged other dark features on Titan, but this is the first with a smooth shape suggesting a shoreline. The others have displayed angular or diffuse edges.

Scientists caution the dark filling might not be liquid. Says imaging team leader Carolyn Porco (Space Science Institute, Boulder, Colorado), "It's plausible the 'lake' is simply a broad depression filled with dark, solid hydr cArbons⌧ ⌧ alling frsm the a⌧ osphere." In this cdse, he smooth outline would result from some geological activity, such as the collapse of a sinkhole or a volcanic caldera.

n T ta.'s skuthern hemisphere, temperatures are ro ⌧ ⌧ –300° F (vs ⌧ ⌧) a d methane fills many the roles tha⌧ o ater filks on Earth. Thus, on Titan, methane ra⌧ d⌧ can fa⌧ l from t thnn ⌧ cloud- , and meth ane s e$ s may erode solid methane hills and ridges.

Since Cassini's arrival, planetary scientists have been searching Titan in vain for the open bodies — seas or lahe — of⌧ iquid⌧ hydro arbons th⌧ t thdoryqp Further encounters with the moon should help determine the newly discovered feature's nature, and perha q its orighn. — **ROBERT BURNHAM**


NASA/JPL/SSI

LAKE METHANE. **The dark oval marks what may be a methane lake lying close to Titan's south pole (red cross). The brightest features seen in this image, taken June 6, 2005, are methane clouds.**

NASA/JPL/CALTECH

PACK SUNSCREEN. **Astronomers have found the first planet in a triple-star system.**

Planet of the three stars

Sunsets would be colorful on HD188753b, a Jupiter-like planet with three suns to call its own. The planet orbits a yellow star once every 3.5 days, but another pair of stars orbits about as far out as Saturn orbits our Sun. The system lies 149 light-years away in Cygnus.

Caltech astronomer Maciej Konacki's report on HD188753b appeared in the July 14 *Nature*.

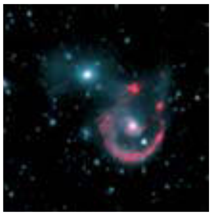
—**JEREMY McGOVERN**

Galaxy "smiles" after c llisqon

In December 2004, a team led by Beverly Smith of East Tenne se(Sta!e University studied the interacting galaxies Arp 107 in Leo Minor using the Spitzer Space Telescope.

At 3.6 microns, Spitzer sees stars throughout the two galaxies. But younger stars haven't strayed far from their dust-rich birth clouds. Dust heated to about 1,300° F (730° C) by young stars emits strongly at 8 microns.

These young star clusters give Arp 107 a Cheshire cat-like grin, the result of a density wave


NASA/JPL-CALTECH /B. SMITH ET AL.

FENDER BENDER. **Young clusters nred) trace star formation t⌧ gg⌧ re by Ar 107's collision.**

spreading across the galaxy after the collision.

Older clusters lie on the left side of the "smile," younger clusters lie on the right.

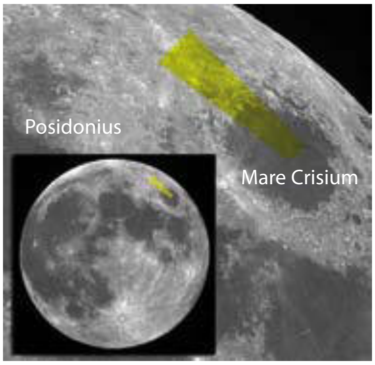
Smit⌧ p(esented the images at the American Astronomical Society's summer meeting in Min eapoli⌧— **F. R.**

Sun flash shows Moon's calcium

On January 15, an intense solar flare blasted X rays across the solar system as scientists calibrated instruments on the European Space Agency's SMART-1 lunar orbiter.

When the blast hit the Moon, surface rocks glowed in X-ray wavelengths characteristic of the elements making them up. The flash helped SMART-1 distinguish calcium, aluminum, silicon, iron, and other surface elements.

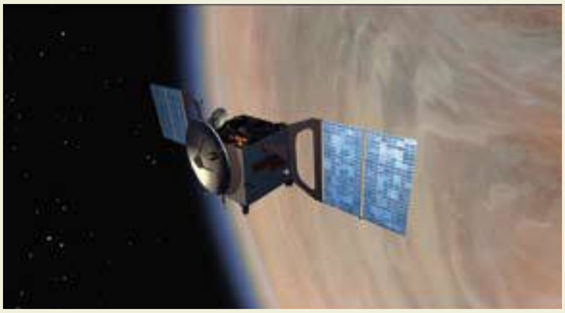
"The Sun was kind to us," says Manuel Grande of the Rutherford Appleton Laboratory, who leads the mission's X-ray spectrometer team. "It is the first time that calcium has been unambiguously detected on the Moon by remote-sensing instrumentation." — **F. R.**



ESA/D-CIXS; MOON: NOAO/AURA/NSF/T. A. RECTOR

SUN AS IS **ESA's SMART-1 detected calcium and other elements in Mare Crisium (scanned section in yellow).**

Doing Venus on the cheap



ESA

SPENDING SOME INHERITANCE. **Europe's Venus Express mission will use mostly existing instruments and hardware built for other missions. With the spacecraft, scientists hope to learn more about the venusian atmosphere and the planet's chemical history.**

At the dawn of the Space Age in the early 1960s, Venus was the easiest planet to reach from Earth. Velocities were lowest, and the travel times shortest. Now, after a decade of neglect, a mission to Venus may make its mark as the *cheapest* such project.

That's because Europe's Venus Express probe, due for launch October 26 aboard a Russian rocket, has been assembled from leftover parts, using mostly pre-existing blueprints.

Yet the amazing thing about such a bargain-basement project is the value of the planetary science data it will collect from orbit above Venus.

Venus retains a number of mysteries, in particular concerning its atmosphere. Scientists lost interest in these after the Magellan mission ended in 1994, largely from puzzlement about how to solve them.

High on the list is what drives the high-speed, global winds that scientists call "super-rotation." Additional problems focus on understanding the planet's atmospheric chemistry.

Says the project's web site, "Analyzing and understanding the prevailing conditions in the atmosphere and in the near environment of Venus is of critical importance to understanding long-term climatic processes governing the evolution of life on Earth."

For a probe designed to orbit a cloud-shrouded world, Venus Express will be loaded with cameras.

One is a high-speed imager for capturing lightning flashes. Others will observe the clouds in different wavelengths, concentrating, for example, on mysterious ultraviolet absorption features about 50 miles (80 km) above the surface.

Scientists don't have enough information even to theorize seriously about these absorption patches. This allows wild speculation that they might even be acid-eating microbes using ultraviolet radiation in some kind of photosynthesis. The real explanation may be more bizarre.

Another instrument will measure the temperature of the atmosphere between 35 and 60 miles (55–100 km) and lower.

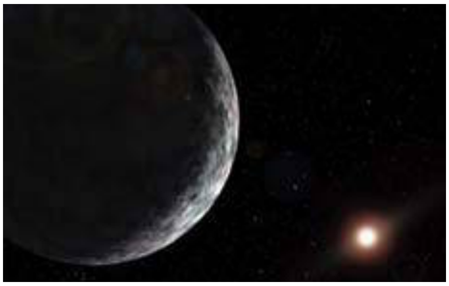
It also can measure the surface temperature, revealing any volcanic activity. The probe will study how the solar wind, undeflected by the planet's weak magnetic field, affects the atmosphere.

The spacecraft uses hardware already built for Mars Express and the Rosetta comet mission — only two instruments are actually new.

For all its promised contributions, Venus Express may not be able to contribute to a bigger question: why Venus rotates at a rate close (but not precisely) in sync with Earth. Its backward spin turns the same face toward Earth at every inferior conjunction, as Venus passes between Earth and the Sun.

Gravity's effects are too weak to account for this, and most scientists think it's only a cosmic coincidence and doesn't even need an explanation.

But it's just one more mind-boggling feature of this still poorly understood neighbor world. **— JAMES OBERG**



NASA/JPL-CALTECH

TENTH ROCK FROM THE SUN. **Astronomers welcome an ice world bigger than Pluto — dubbed 2003 UB_{313} — to the solar system.**

Tenth planet discovered

On July 29, Caltech astronomer Michael Brown announced his team had discovered a new planet both larger and more distant than Pluto. The new object — dubbed 2003 UB_{313} — is the farthest directly observed body in the solar system and the fourth brightest Kuiper Belt object.

Not all astronomers agree with the team's planetary claim, despite NASA's apparent approval. During the past few years, many researchers — Brown among them — have argued Pluto itself should no longer be classified as a planet. But, he now reasons, if we're comfortable conferring planetary status on Pluto, larger bodies deserve the title, too.

2003 UB_{313} now lies 97 AU from the Sun (1 AU is the Earth-Sun distance), more than 9 billion miles (14.5 billion km), and has reached the farthest part of its 560-year orbit. About 280 years from now, it will reach its closest point to the Sun at a distance of 38 AU.

The amount of light the planet reflects helps scientists determine its size. But, says Brown, "Even if it reflected 100 percent of the light reaching it, it would still be as big as Pluto." However, there is no substance known this reflective, and the less shiny the object's surface is, the larger it would be. If 2003 UB_{313} reflects 90 percent of sunlight — the same as a fresh snowfall on Earth — Brown says its size would be a few percent larger than Pluto.

He estimates 2003 UB_{313} is "probably one-and-a-half times the size of Pluto," or about 2,075 miles (3,340 km) across.

The team plans to view the object with the Hubble Space Telescope soon. **— F. R.**

UNSUNG HEROES. Beginning in 2008, the Kavli Foundation will award three $1 million prizes every 2 years to recognize scientists working in the areas the foundation focuses on: astrophysics, nanoscience, and neuroscience.

Stellar halos may hold cosmic clues

The timing of the universe's reionization left its mark on the Milky Way's stellar halo, say astronomers. The sooner this reionization occurred, the more concentrated our galaxy's stellar halo should be.

The universe began as an ionized cloud of atomic nuclei and free-ranging electrons. As it cooled, electrons combined with hydrogen and helium nuclei and the universe became neutral. When the first stars and quasars began to shine, electrons were ripped from the gas. The exact timing of this reionization is unknown. It may have occurred as early as 100 million years after the Big Bang, or when the universe was 900 million years old.

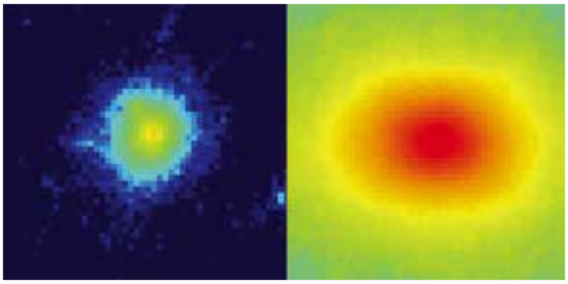
Now, Kenji Bekki of the University of New South Wales in Sydney, Australia, and Masashi Chiba of Tohoku University in Sendai, Japan, have proposed a way to determine when reionization occurred: Observe the concentration of a galaxy's stellar halo. Their work will be published in *Astrophysical Journal Letters*.

Computer simulations of a developing galaxy showed the sooner reionization occurred, the sooner the galaxy's fragments ceased star formation.

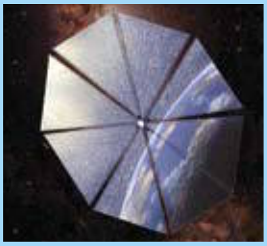
Stars first formed in the densest clumps of gas. These clumps merged to form a stellar halo. Smaller clumps joined later and added material to the outer part of the halo. Stars from these smaller clumps, if present, would have smeared out the halo. But if reionization occurred early, these latecomers would be starless and wouldn't alter the halo's tight concentration.

The astronomers say the Milky Way's actual stellar halo matches their model in which reionization occurred at 260 million years after the Big Bang.

Bekki and Chiba suggest astronomers use large ground-based telescopes to observe other giant spiral galaxies' stellar halos. These observations should further constrain the epoch of reionization. — **KEN CROSWELL**



FINDING A MATCH? If the universe reionized early, at redshift 15, it should have created compact stellar halos (left); if later, at redshift 6, stellar halos should be more diffuse. *ASTROPHYSICAL JOURNAL LETTERS*/KENJI BEKKI AND MASASHI CHIBA



R. STERNBACH/THE PLANETARY SOCIETY

MAYBE NEXT TIME. Cosmos 1 would've sailed through space powered by solar wind.

Cosmos 1 lost

The first solar-sail spacecraft, Cosmos 1, was lost shortly after launch from a Russian submarine in the Barents Sea June 21.

Plans called for the craft to reach a 500-mile orbit in 4 days, after which its sails — with a total surface area of 6,500 square feet — would have deployed. Sunlight hitting these reflective and lightweight sails would have propelled the craft.

— **LIZ KRUESI**

First stars? Not yet.

Two first-star candidates have enough heavy elements to indicate they formed from material processed by a still-earlier generation of supernovae.

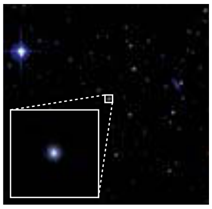
Surviving first-generation stars' spectra would have almost no "metals" — elements heavier than helium.

Astronomers agree the two hyper metal-poor (HMP) stars HE0107–5240 and HE1327–2326 formed soon after the Big Bang, but debate their first-generation status.

Ken'ichi Nomoto (University of Tokyo) and colleagues used computer simulations to reproduce the ratios of elements found in the two HMP stars. Their findings are published in *Science* (June 3, 2005).

The group found the amount of metals ejected into space depended on the stars' rotation speed. Different rates could reproduce the precise mix found in the HMP stars.

— **ROBERT ADLER**



STScI/AAO/ROE

TOO MUCH BLING? HE1327–2326 has the least amount of iron known, yet it still may be too metal rich.

Battle for the night sky

Quebec astronomers, the Mont Megantic Observatory, and surrounding towns, are establishing a 15-mile-wide (25 km) dark-sky preserve centered on the observatory.

Mont Megantic is about a 3-hour drive east from Montreal.

Satellite images taken during 1997 show Montreal suffering the same amount of light pollution as New York City, with less than one-quarter its population.

The organizations partnered with the Quebec Federation of Amateur Astronomers to produce a manual on reducing urban light pollution that any city can put into practice.

— **ANDREW FAZEKAS**

NASA/GSFC/NOAA/NGDC/DMSP DIGITAL ARCHIVE

NIGHT LIGHT. This image shows the widespread influence of light pollution.

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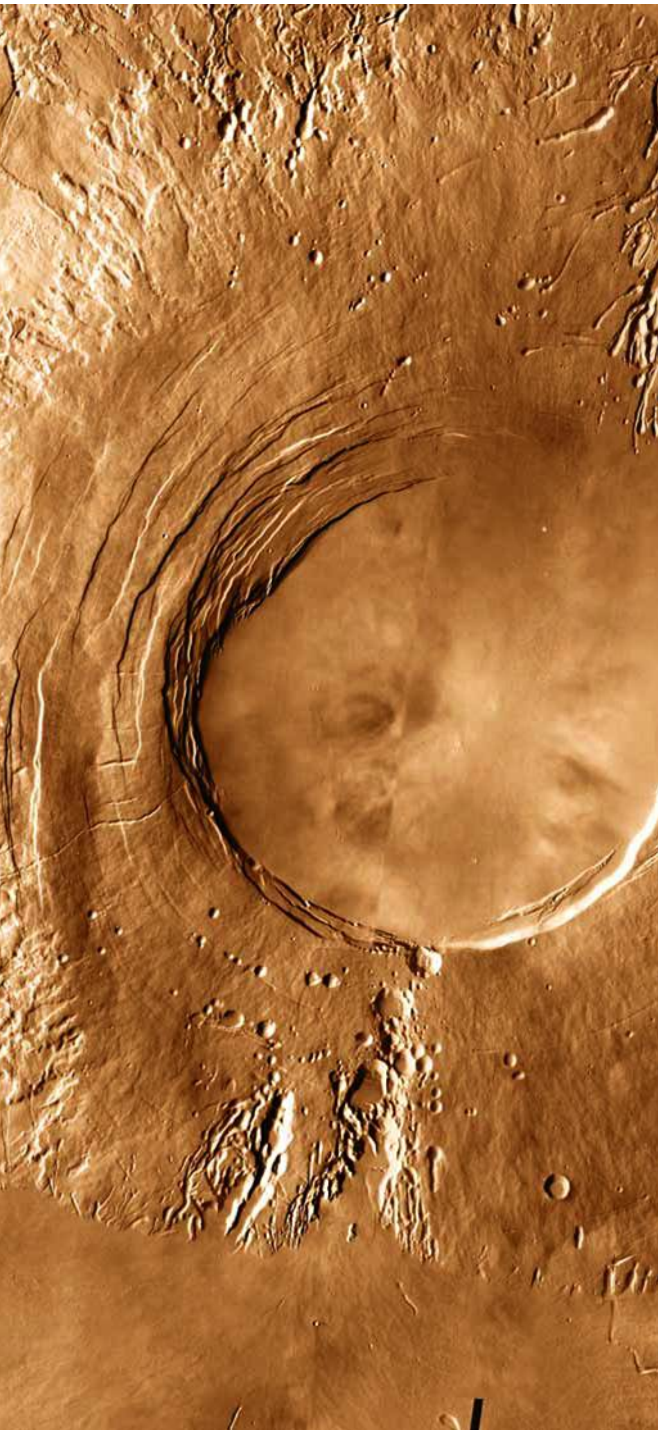
TANG, IT'S NOT. The European Space Agency created 11 meals using ingredients that can be grown on Mars in greenhouses. Recipes include "Mars bread with green tomato jam." Haute cuisine indeed.



NASA/JPL/ASU IMAGE 20050613A

Arsia Mons caldera

LAVA MOUNTAIN. Southernmost of Mars' Tharsis volcanoes, Arsia Mons spans 270 miles (430 km). The volcano's summit caldera (seen here) spans 72 miles (115 km) across. The island of Hawaii, known as the Big Island, would fit inside this volcano's caldera. The Mars Odyssey spacecraft's THEMIS imager took this infrared mosaic.

NASA/JPL/CORNELL

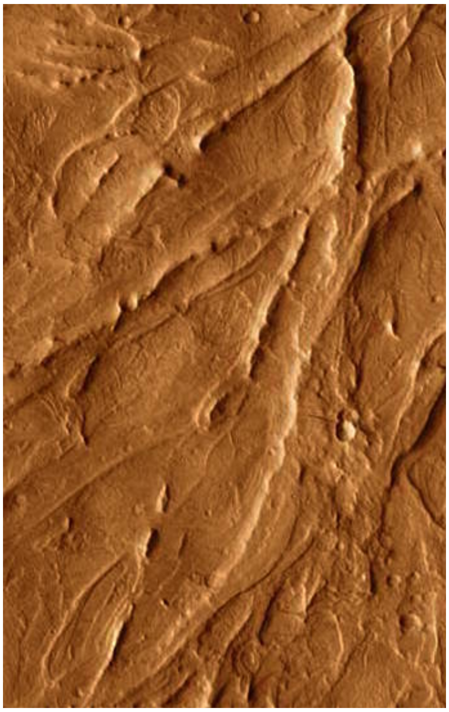
CLINGY DUNE. Deep ruts show where Opportunity spun its wheels.

Oppy gets unstuck

Purgatory Dune let go of Mars rover Opportunity June 10, after the rover was mired for a month.

Then, project scientists drove the rover east before turning south toward Erebus Crater.

In Gusev Crater, rover Spirit is driving up Husband Hill. Scientists hope to see the hill's south side, where orbital images suggest layered sedimentary deposits exist. — **R. B.**



NASA/JPL/MSSS IMAGE S05–00077

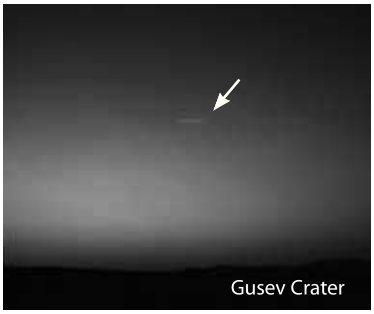
RAISED BEDS. Channels overlap in sedimentary rock, intersecting as they weave a complex pattern in this view of Mars' Aeolis region. Raised channels occur when tougher material fills existing channels and the softer surroundings then erode. This Mars Global Surveyor image, lit from the upper left, spans about 2 miles (3 km).

Martian meteor shower

A streak in the sky caught last year by Mars rover Spirit is the first martian meteor ever observed, says a team of scientists. The team analyzed the meteor's path and says it belongs to an annual meteor shower coming from Comet Wiseman-Skiff.

The meteor was seen in the predawn sky over Gusev Crater March 7, 2004 (sol 63 of Spirit's mission). The meteor, traveling southward 14° above the eastern horizon, appears in a green-filtered Pancam image.

"Comet Wiseman-Skiff is among the top five candidates for producing a regular martian meteor shower," writes the team, led by Franck Selsis (École Normale Supérieur, France), in *Nature* (June 2, 2005). Selsis notes this meteor shower would have reached peak activity March 11, less than 4 days after the streak was imaged. — **R. B.**



NASA/JPL/CORNELL

SHOOTING STAR. A meteor (arrow) from a martian shower streaks through Gusev Crater's predawn sky.

SCOPE MODE
2004/8/10 16:18
SCOPE
RA 7h22.0m
Dec 0° 0'
Alt 0° 0'
Az 90° 0'
TARGET
RA 8h 0.0m
Dec 10° 0'
Alt 0° 0'
Az 270° 0'
Alignment
0 Point(s)
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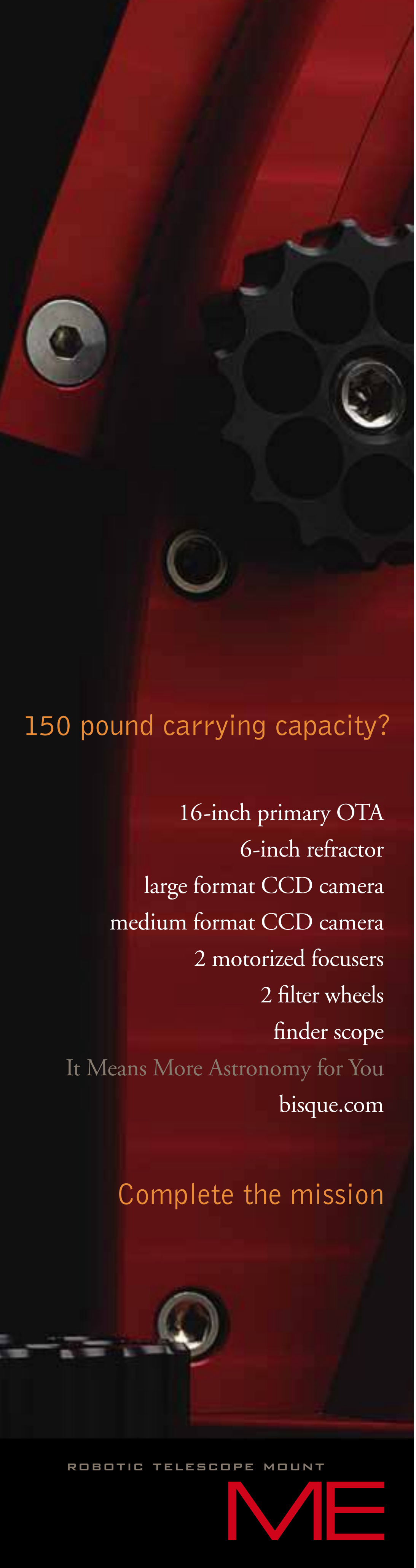
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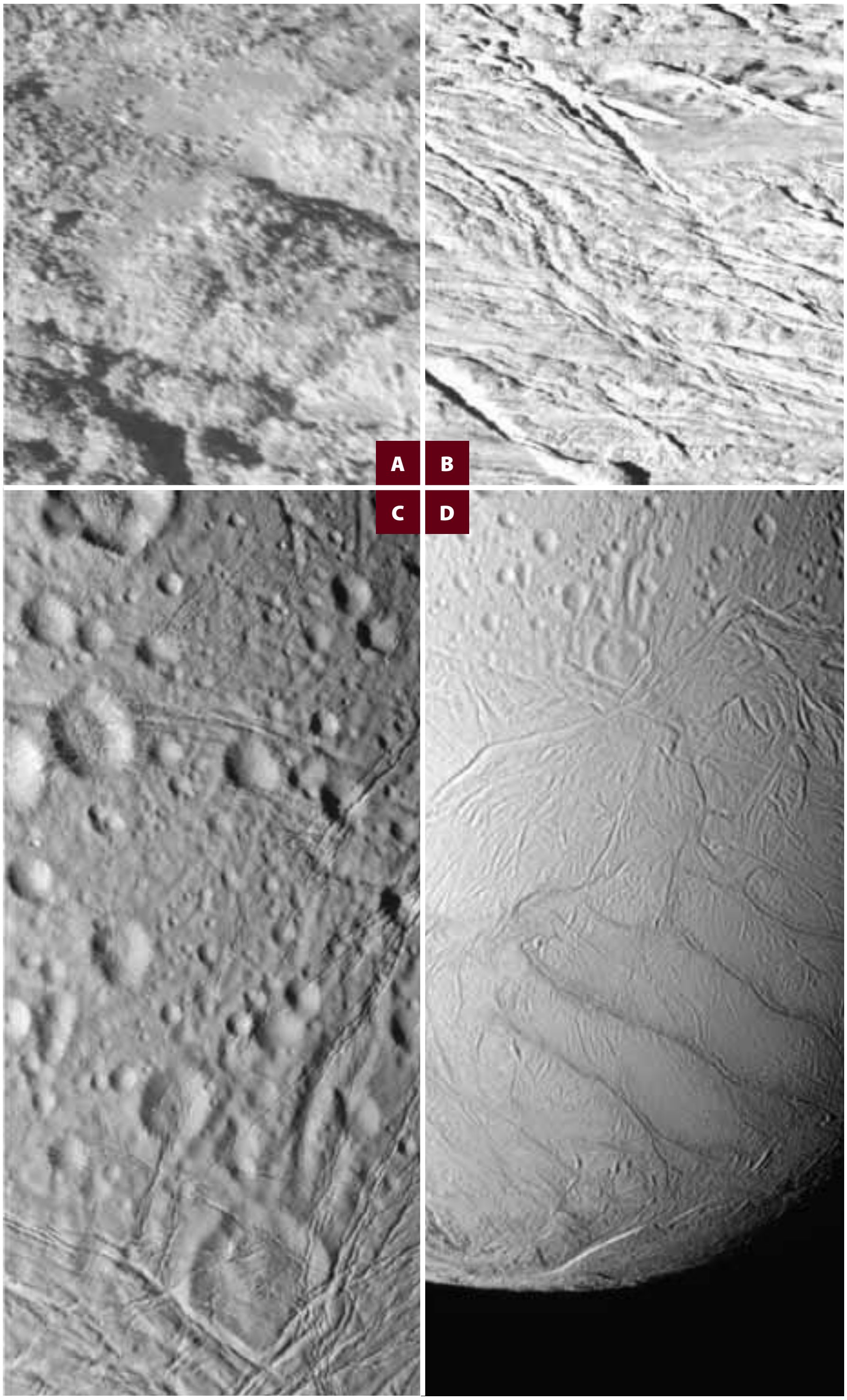
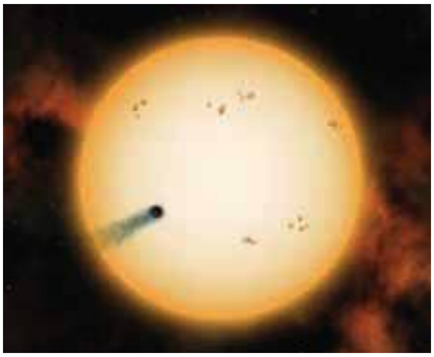


NASA/JPL/SSI

Cassini takes a close look at Enceladus

ENIGMATIC BUMPS AND BOULDERS. In mid-July, the Cassini spacecraft made its closest pass by any moon in the tour so far, missing Saturn's moon Enceladus by 108 miles (175 km). [A] Near closest approach, Cassini imaged house-size boulders. [B] On coarser scales, it saw relief that shows tectonic activity operates on local [C] and global [D] scales.



LYNETTE COOK

HOT ROCK. **Its atmosphere at 2,000° F, an exoplanet weighing 70 Earth-masses orbits the star HD 149026 every 2.9 days.**

Exoplanet supports formation theory

A team of astronomers announced in June they discovered an extrasolar planet with the largest core of any known previously. Led by Debra Fischer (San Francisco State University), the team used the transit method, which uncovers the planet by detecting a minute reduction of starlight as the planet passes in front of the star HD 149026 (about 250 light-years from Earth).

By observing stellar transits, says Fischer, "We can calculate the planet's physical size, whether it has a solid core, and even what its atmosphere is like." Its upper atmosphere, she notes, is about 2,000° F (1,100° C).

The planet circles HD 149026 every 2.87 days, Fischer says. Its mass roughly equals that of Saturn, but it has a smaller diameter. Modeling of the planet by Peter Bodenheimer (UC Santa Cruz) shows it likely has a solid core of about 70 Earth-masses.

The finding has implications for planet-making theories. As the team members attempted to find a plausible scenario for making the planet, they theorized it could have formed by the collision of two protoplanets, each with a core mass of 35 Earths.

The large core suggests this planet began by forming its core first; then it attracted a gaseous envelope. This supports the "core-accretion" model for planetary formation over the main competing theory in which planets form as dense gas clouds collapse. — **R. B.**

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SPECIAL COSMOLOGY ISSUE

Making multiverses

Cosmic inflation, string theory, and the cosmological constant all suggest there's more to the universe than the part we can see, reports **Steve Nadis**.

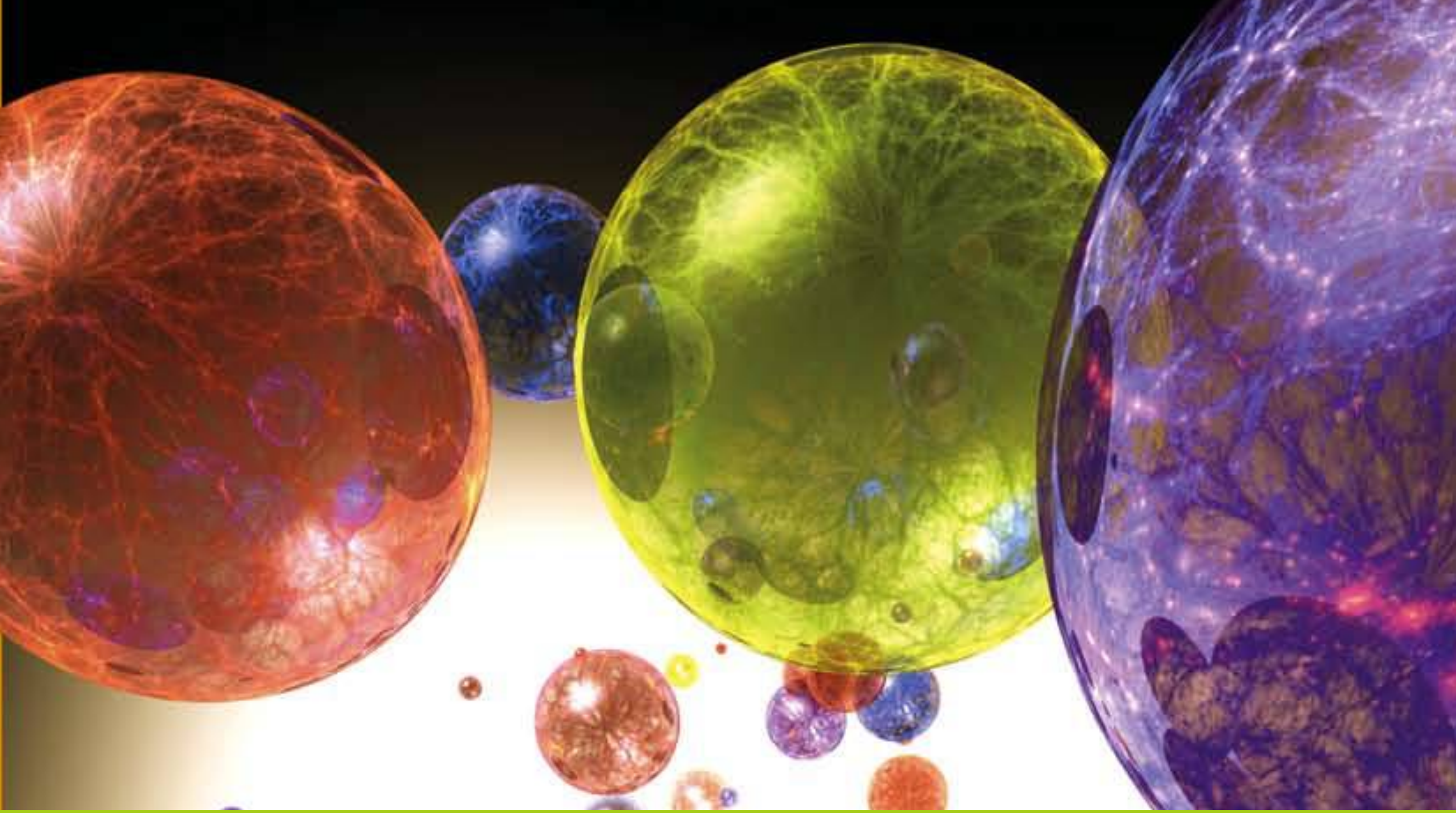
More than 400 years ago, the Dominican monk Giordano Bruno was burned at the stake for making a heretical claim: that our universe was infinite and contained an infinite number of worlds.

Today, cosmologists arguing a similar point — that our universe is but one of many universes comprising a larger "multiverse" — are hoping for a better fate, maybe even a Nobel Prize. There is growing acknowledgement among physicists and astronomers that this idea, outlandish as it sounds, just might be true.

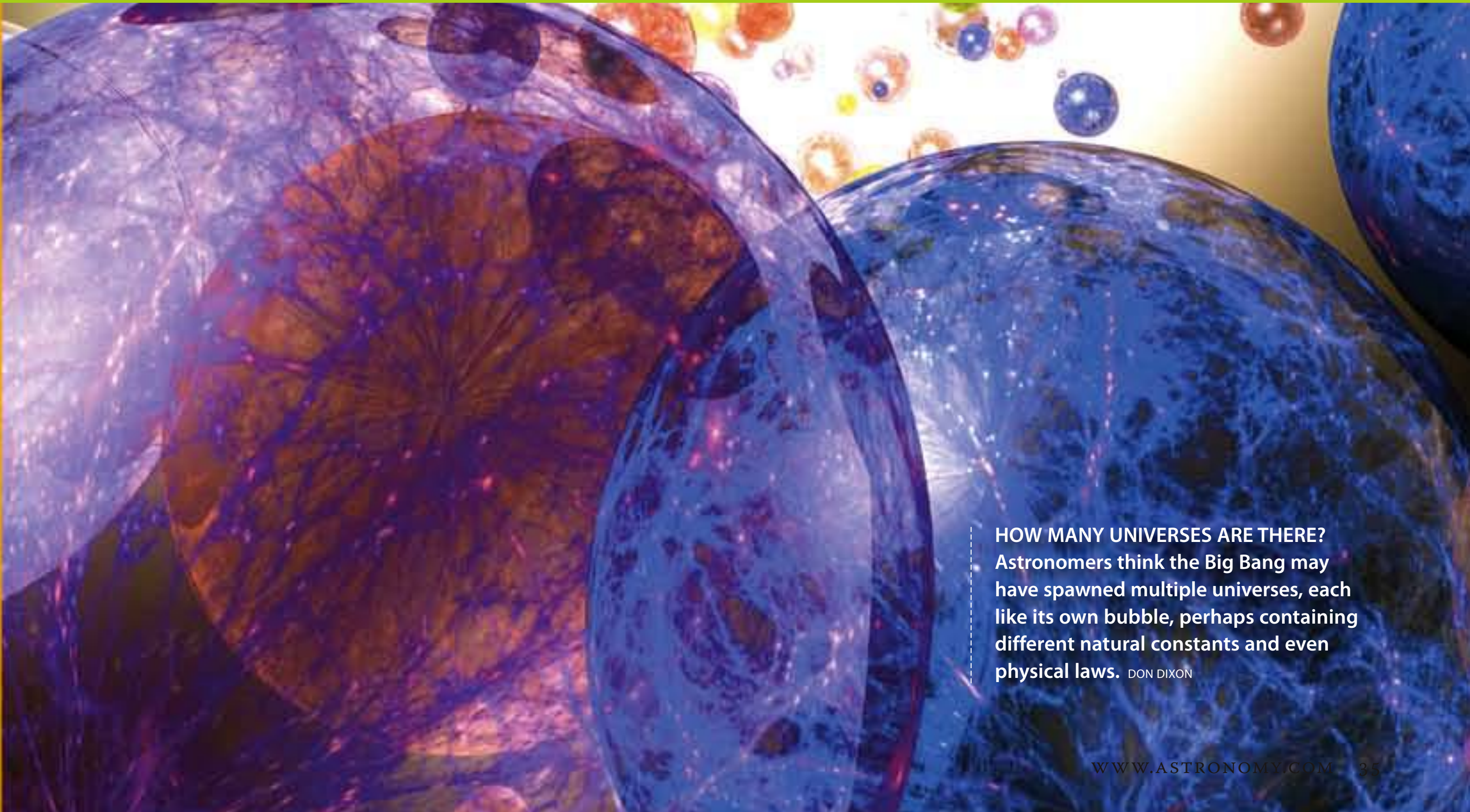
One picture emerging from cosmology, astronomical observations, and particle physics is that there's a lot more to the universe than we can see: The universe is not only vast, extending far beyond the visible portion, it may be composed of distinct, exponentially large regions with wildly divergent features. For all practical purposes, these realms could be regarded as separate universes within an all-embracing multiverse.

While schemes exist for multiple or parallel universes, one promising approach reflects what Harvard physicist Nima Arkani-Hamed calls "the confluence of things now pushing us toward the notion of a multiverse."

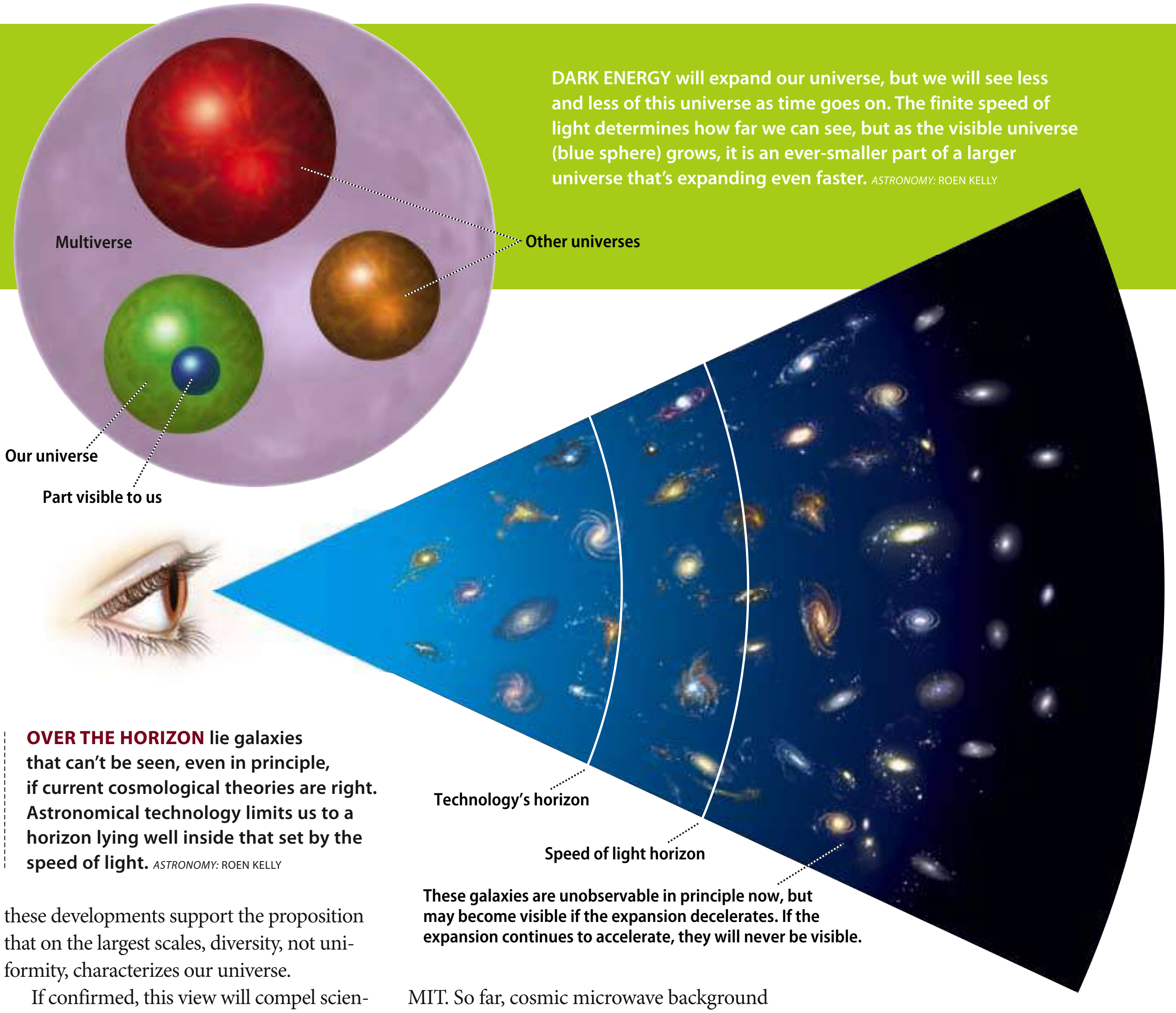
These include: measurements that indicate the universe's expansion is accelerating; empirical tests that bolster the inflationary universe scenario; theories of eternal inflation that suggest an endless number of Big Bangs; and recent developments in string theory that show how to design universes with widely different properties. Collectively,



> "I fully expect the true nature of reality to be weird and counterintuitive, which is why I believe these crazy things." *—Max Tegmark*



HOW MANY UNIVERSES ARE THERE? **Astronomers think the Big Bang may have spawned multiple universes, each like its own bubble, perhaps containing different natural constants and even physical laws.** DON DIXON


Multiverse
Other universes
Our universe
Part visible to us
Technology's horizon
Speed of light horizon
These galaxies are unobservable in principle now, but may become visible if the expansion decelerates. If the expansion continues to accelerate, they will never be visible.

DARK ENERGY will expand our universe, but we will see less and less of this universe as time goes on. The finite speed of light determines how far we can see, but as the visible universe (blue sphere) grows, it is an ever-smaller part of a larger universe that's expanding even faster. *ASTRONOMY:* ROEN KELLY

OVER THE HORIZON lie galaxies that can't be seen, even in principle, if current cosmological theories are right. Astronomical technology limits us to a horizon lying well inside that set by the speed of light. *ASTRONOMY:* ROEN KELLY

these developments support the proposition that on the largest scales, diversity, not uniformity, characterizes our universe.

If confirmed, this view will compel scientists to extend the Copernican Revolution, according to Cambridge University's Sir Martin Rees. "We've gone from thinking about different worlds within our universe, to thinking about entirely different universes."

Far horizon in view

Starting on the simplest level, we know the universe stretches far beyond the limits of our telescopes. At present, our "horizon" is about 14 billion light-years (actually about 40 billion light-years, considering that the stuff we've seen has already expanded farther). We call a sphere of that radius a Hubble volume.

Observers 100 billion light-years away would inhabit a completely different Hubble volume than ours, notes Max Tegmark of MIT. So far, cosmic microwave background measurements show the universe to be flat to a precision of about 1 percent. If space is ultimately curved, says Tegmark, its radius of curvature is at least 10 times bigger than the horizon. This means our universe contains at least 1,000 separate Hubble volumes.

According to inflation theory, the universe stays flat forever. In other words, the universe is infinite, and strange things can happen in infinite space. Work by Jaume Garriga of the University of Barcelona and Alexander Vilenkin of Tufts University shows such a universe would have an infinite number of observable universes, or "O-regions." Each of these spatially finite O-regions has a finite number of possible histories. History thus repeats itself, over and over.

"Whenever a thought crosses your mind that some terrible calamity might have happened, you can be sure it has happened in some of the O-regions," Garriga and Vilenkin write. "If you nearly escaped an accident, you were not so lucky in other regions with the same prior history."

Vilenkin finds this somewhat depressing because it suggests we're not special. But he considers the logic airtight: If the total number of possible histories is finite and the number of regions infinite, there's no other conclusion to draw. Tegmark, who received tenure from MIT this year, isn't depressed by the prospect of not getting tenure in other universes. Moreover, he actually *believes* this stuff.

"Whenever you go beyond human scales, counterintuitive things should happen, and that's exactly what we've seen in the last century," he says. "If we go very fast, time slows down. If you make a star very massive, eventually you'll get a black hole. If you make something very small, it can be in two places at once. I fully expect the true nature of reality to be weird and counterintuitive, which is why I believe these crazy things."

Steve Nadis, *a frequent contributor to* Astronomy, *is never happier than when writing about the weirder aspects of the universe we live in. His home base is Cambridge, Massachusetts.*

> “We’ve gone from thinking about different worlds within our universe, to thinking about entirely different universes.” —*Sir Martin Rees*

If you want crazy, consider this: Inflation, the explosive growth spurt that started and stopped before our universe was 10^{-30} second old, never really ended. It stopped in our region, of course, giving rise to the bubble universe (or O-region) we call home. But the process continues unchecked elsewhere, spawning new bubble universes along the way.

Eternality, a feature of almost every inflation model, occurs because inflation is driven by an unstable material (called a false vacuum) that decays over time. But this material expands even faster than it decays, so expansion wins out, and inflation never ends.

Bubble universes

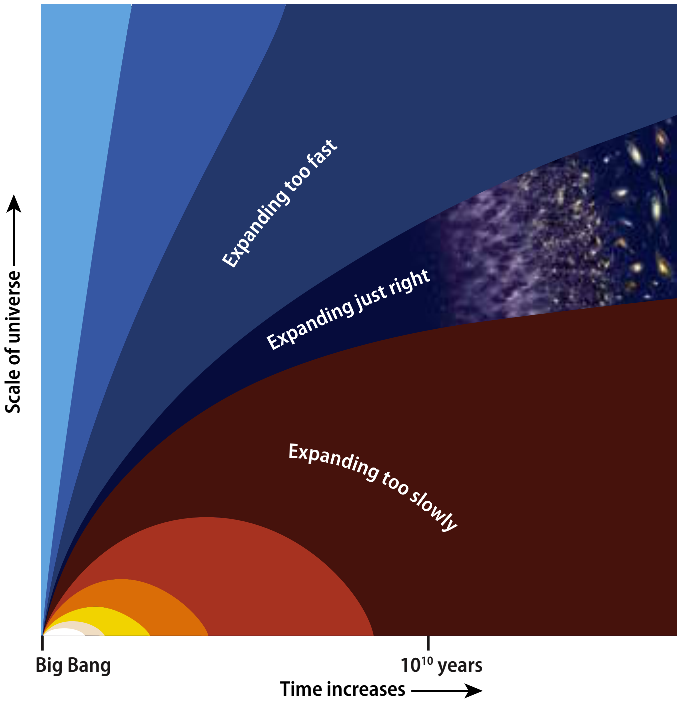
Eternal inflation creates a different kind of universe than the simple sphere we once envisioned. Think of Swiss cheese instead. Each hole represents a bubble universe; the cheese represents the space between the bubbles and is expanding faster than the speed of light. Not only do the bubbles get farther and farther apart, new bubbles keep forming within the cheese — the result of new Big Bangs popping off in a never-ending chain reaction. Eternal inflation doesn’t just produce an oversized hunk of cheese; it produces a multiverse.

How convincing is this scenario?

“Many, no doubt, would call it a house of cards, but from my point of view, it looks very plausible,” says MIT’s Alan Guth, generally credited as inflation’s inventor. Inflation has been very successful in making predictions — flatness, homogeneity, and scale-invariance — for the part of the universe we can observe, he says, “which means we should also take seriously its predictions for parts of the universe we can’t observe.”

As scientists, adds Tegmark, “We’re not testing the general idea of a multiverse. We’re testing inflation — a mathematical theory that predicts a multiverse and all kinds of other stuff.” So far, inflation has passed all empirical tests to date, but the idea faces even more rigorous challenges coming later this decade and beyond.

OUR COSMIC FATE hangs on the universe getting the parameters right, or nearly so. If the universe expands too fast (scenarios shown in cool colors), stars and galaxies don’t coalesce and form. And if the universe does not expand fast enough (scenarios shown in warm colors), it never cools sufficiently — or there’s no time for stars to evolve before everything falls back together in a big crunch.



ASTRONOMY: ROEN KELLY

“We still have no idea whether there is one universe or many,” says Rees. Yet at a 2003 Stanford University conference, he was confident enough of the multiverse’s existence to stake his dog’s life. Stanford’s Andrei Linde went further, claiming he would put his own life on the line.

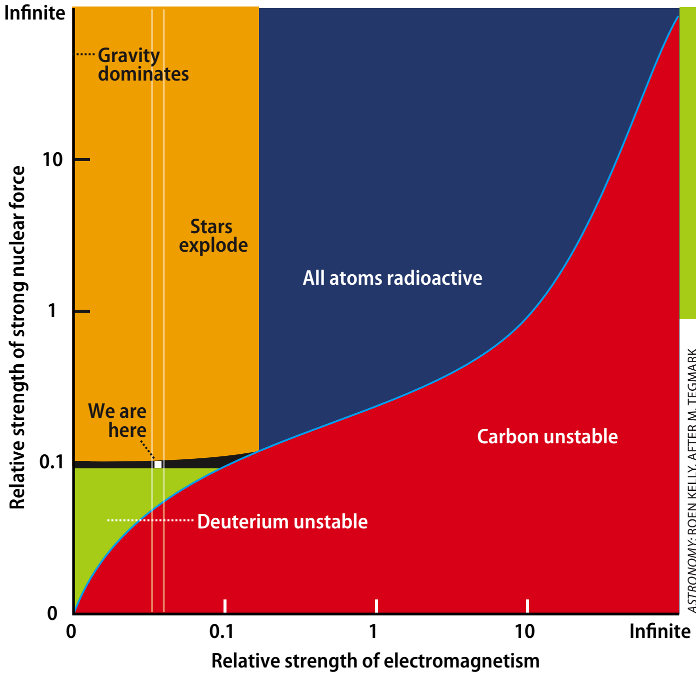
Worlds of worlds

Let’s suppose the eternal inflation theorists — Vilenkin, Linde, and Guth — are right, and universes are churned out in assembly-line fashion. Are these universes as indistinguishable as the Model Ts produced 80 years ago, or is some variation allowed? “That’s a question for fundamental physics to address,” says Vilenkin, who suggests the answer may come from a new idea called the “landscape of string theory.”

The landscape — a term coined by Stanford physicist Leonard Susskind — stems largely from the fact that string theory requires 9 or 10 dimensions of space and one of time. The world we inhabit has three dimensions of space and one of time, which means the additional six or seven spatial dimensions need to be hidden — rolled up into toruses (donuts), for example, or wrapped into more complex shapes.

This bundling can be done in an estimated 10^{500} ways, each of which represents a stable configuration of space-time called a vacuum. Although string theory has one overarching set of laws, the specific rules governing each vacuum — as well as the vacuum energy, number of dimensions, types of particles and forces — depend on the geometry of the extra dimensions.

The scenario, in effect, allows for a huge number of conceivable worlds or universes,



ASTRONOMY: ROEN KELLY, AFTER M. TEGMARK

PHYSICAL CONSTANTS took on values given by chance processes when the universe was born. But if they were any different, we couldn't exist.

which can be pictured as random valleys, situated at slightly different elevations and spread across an immense landscape of possibilities.

The multiple universes that arise in string theory have nothing to do with inflation, yet the two ideas are complementary. "Eternal inflation shows you how to spin off multiple universes," explains Joseph Polchinski of the University of California, Santa Barbara. "The landscape shows you how those universes can have different physics."

Although it sounds like a happy union, not everyone is cheering. Inflation pioneer Paul Steinhardt of Princeton considers the landscape concept a step backward for physics. "We had hoped string theory would tell us how inflation really works," he says. "Instead, we're told the universe is much more complicated on large scales than we ever imagined, with inflation occurring in a large number of ways that vary from region to region."

"There's nothing surprising about theories that have lots of solutions," counters Susskind. "Any time you have many variables, you can expect a large number of solutions." Just as we accept biological theories that allow for millions of different species, we might have to accept physics theories that allow for many different vacuum states.

Physicists had hoped that string theory would explain our world with one solution, not a multitude. Polchinski, among others, shared that view, but now tries to keep an open mind. "Our job is to figure out the way nature is," he says, "not to tell it how to behave."

At this stage, it would be premature to consider the landscape a reality. Our understanding of string theory is still "tentative," Polchinski admits. "Every 5 to 10 years, we learn something that surprises us, which shows we don't have the full picture. Yet the evidence for the landscape is piling up, and it's time to start taking the idea seriously."

Dark energy

One of the strongest arguments in favor of string theory's landscape relates to the energy of empty space — the vacuum energy, or "dark energy." The standard explanation for this energy is that it maintains a single, unwavering value throughout space — thus becoming what Einstein called the cosmological constant.

The problem is that physicists don't know how to calculate the cosmological constant from first principles, the hallmark of a robust theory. The simplest calculations yield a value 10^{120} times bigger than measured values — "by far the all-time worst discrepancy between theory and experiment," notes Susskind.

The answer may come from combining the string-theory landscape, which shows how the cosmological constant can vary, with the "anthropic principle." The latter suggests the cosmological constant may be a variable like the weather — something that changes from place to place in the universe, rather than a true constant of nature.

If a broad range of values for the constant is possible, it's not surprising we live in a universe with a small cosmological constant, one where stars and planets can exist. In the same way, it's not surprising we live on Earth, rather than on Venus or Pluto, where we'd either roast or freeze.

A large positive value for the cosmological constant would produce tremendous

HOW TO SPEAK COSMOLOGY

ANTHROPIC PRINCIPLE
We see the universe the way it is because if it were different, we would not be here to observe it.

COSMOLOGICAL CONSTANT
Originally, this was a mathematical term used by Einstein to give space-time an innate tendency to expand. More recently, it refers to the cosmic expansion produced by dark energy.

DARK ENERGY
A residual energy in space is causing the expansion of the universe to accelerate. Sometimes called vacuum energy.

FLATNESS
A flat universe is one whose space-time sits on the border between eternal expansion and eventual recollapse.

INFLATION
During an early period of extremely rapid growth, the observable universe expanded by a factor of 10^{30} or more in 10^{-32} second.

O-REGION
This is the observable universe, which may be only a fraction of the full universe.

SCALE-INVARIANCE
The spectrum of the cosmic background radiation appears nearly identical at all scales.

STRING THEORY
This is a theory in which the fundamental entities are not particles but tiny string-like loops. Differing loop oscillations correspond to different elementary particles. Strings have length but no other dimension.

“Our job is to figure out the way nature is, not to tell it how to behave.” — *Joseph Polchinski*

cosmic acceleration, and galaxies would never form. A large negative value, conversely, would cause the universe to collapse instantly, and no one would be around to ponder the cosmological constant problem.

Maybe there is a “magical explanation” for the cosmological constant — a mechanism yet to be discovered, says Harvard’s Arkani-Hamed. The alternative is an environmental argument, which requires the existence of many different environments. Fortunately, the landscape provides “zillions” of them, he adds. “Given that the anthropic solution is the only thing that works at the moment, it makes sense to see where this idea leads.”

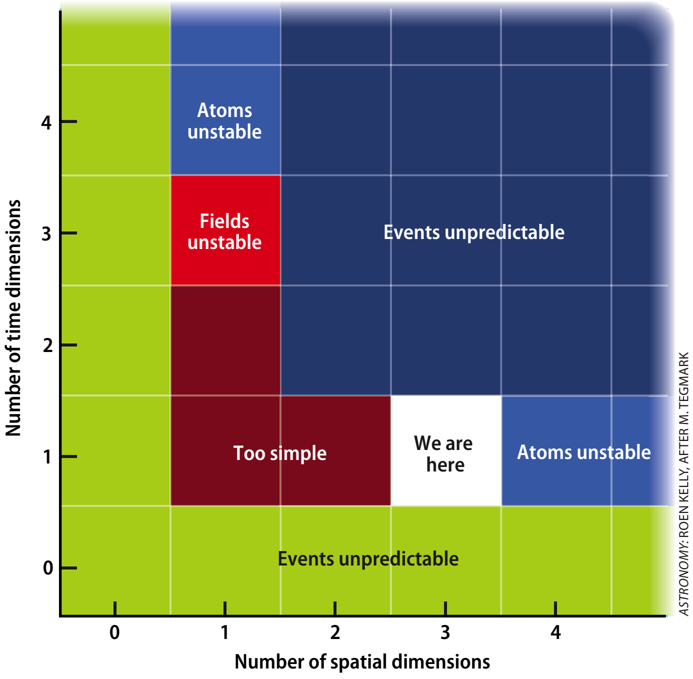
To a certain extent, it leads to trouble. The anthropic principle is widely disliked and elicits strong reactions. David Gross, a physicist at the University of California, Santa Barbara, hates the idea, calling it a “virus” that’s hard to get rid of. Few scientists champion the anthropic principle, although many are resigned to the fact we might be stuck with it.

Last-resort universes?

Tegmark objects to the common practice of considering anthropic arguments “a last resort, which makes it seem like we have a choice.” Any theory, he says, has to address selection effects, including biases stemming from the fact that any universe we observe must be habitable — “and that’s the case whether you call it ‘anthropic’ or not.”

John Peacock of the University of Edinburgh agrees, saying the anthropic principle is “not a retreat from physics but an advance.” Once cosmologists seriously consider the possibility that the vacuum energy can differ from place to place — and that other parameters considered constant may vary as well — they will then need to work out the mechanism responsible for that variation. This can point us toward new physics. In the process, says Peacock, we may learn things about the universe.

SPACE AND TIME might have other values in other universes, but their fates would be quite different.



ASTRONOMY: ROEN KELLY, AFTER M. TEGMARK

But even if the anthropic principle is true, does it really explain anything? And can it help us make actual predictions?

In a 1987 paper, Steven Weinberg of the University of Texas employed anthropic-type reasoning to predict a small, non-zero value for the cosmological constant. If the cosmological constant can assume a range of values, he reasoned, probably it will not adjust itself exactly to zero. “The value we now measure for the cosmological constant is precisely what Weinberg predicted,” notes Polchinski. “It would be great if that’s not a one-time thing and there are other things we can predict.”

It will be hard to use the anthropic principle to determine which worlds, or universes, are most probable, says Linde. The difficulty lies in measuring probabilities for infinitely-large sets. “There are many different ways of counting infinities, and we don’t know which methods are preferable.”

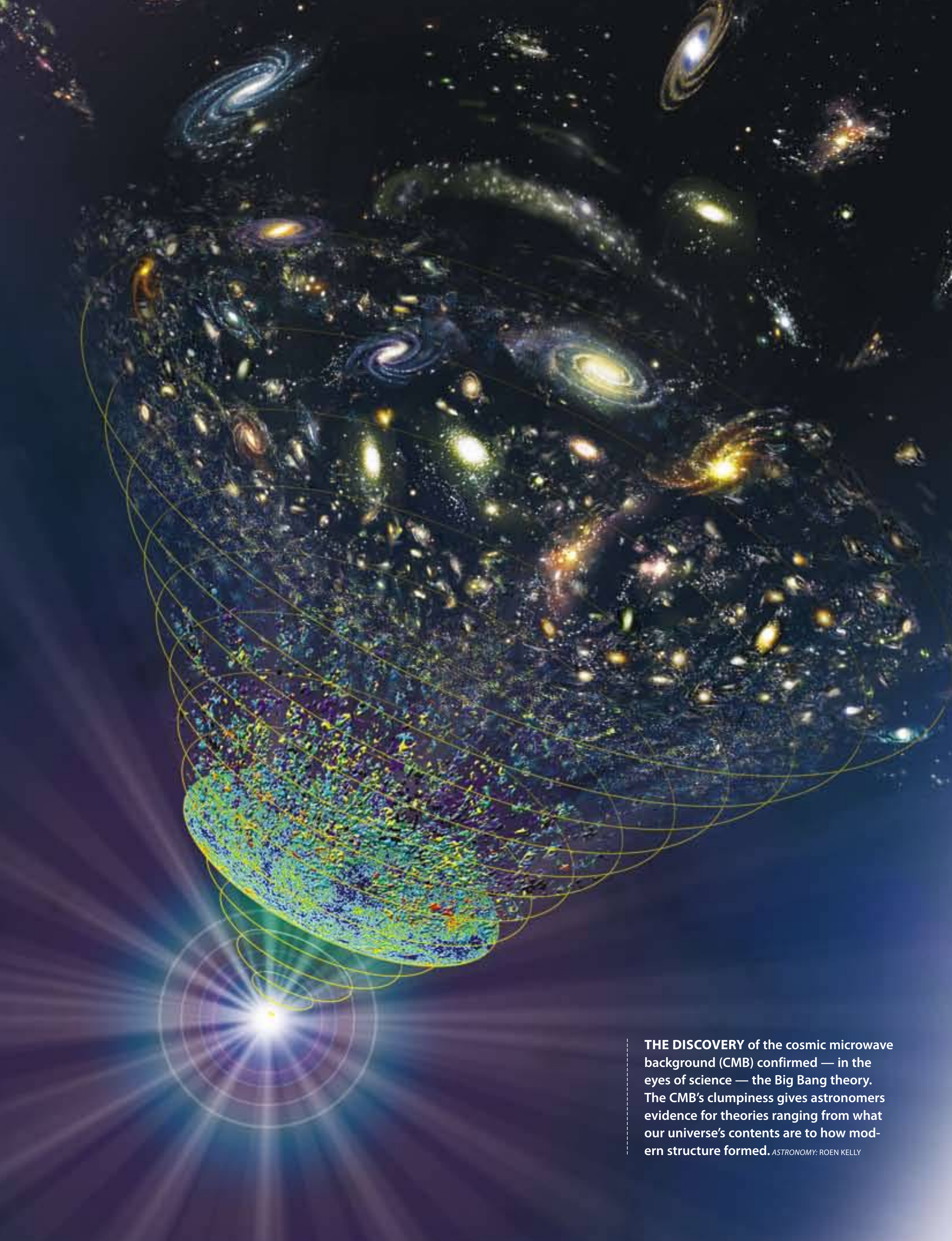
Susskind agrees it will be a long time before we can use the anthropic principle in a predictive way: “At the moment, it’s telling us more about what not to do than what to do.” For example, perhaps we shouldn’t keep trying to explain why the cosmological constant is what it is, he says, “when the only explanation may be that in a universe with a large number of possibilities, we live in an environment that supports life.”

Many versions of the anthropic principle are guaranteed to be true and, therefore, do not meet the standards of science, Vilenkin points out. Before anthropic arguments can carry us further, he says, we’ll need statistical techniques that support testable predictions.

But even if that effort succeeds, there are limits to how far we can go, he notes. “It looks like all we can hope to predict is the probability distribution, saying, for instance, with 90-percent confidence what the mid-range value of the cosmological constant is likely to be.” Sharpening the prediction further may be impossible, due to intrinsic uncertainties.

While some may find that disappointing, Vilenkin says, “were it not for the multiverse picture and anthropic arguments, we’d have no tools for thinking about the structure of the universe beyond our horizon.”

But now there’s a tantalizing, new possibility, he adds: “By doing measurements in our own region, we can test our predictions for what lies beyond.” A



THE DISCOVERY of the cosmic microwave background (CMB) confirmed — in the eyes of science — the Big Bang theory. The CMB's clumpiness gives astronomers evidence for theories ranging from what our universe's contents are to how modern structure formed. *ASTRONOMY:* ROEN KELLY

SPECIAL COSMOLOGY ISSUE

The accident that saved the Big Bang

While adjusting an antenna, two astronomers uncovered cosmic static, leading to one of the greatest discoveries of all time. /// BY JAMES TREFIL

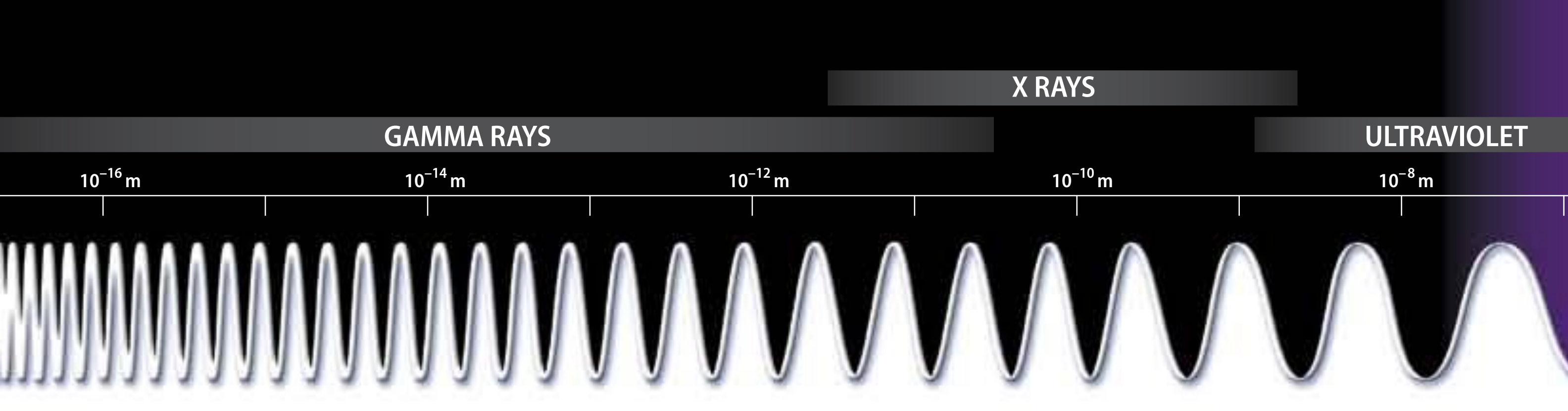
Sometimes the most profound insights come from the most mundane experiences. So it is with the discovery of the cosmic microwave background (CMB), which manifested itself as an engineering nuisance.

You can learn a lot about the history of the universe and the CMB sitting around a campfire. Early in the evening, when the fire is hot, the coals are bright yellow, maybe even white. Later in the evening, before you roll out your sleeping bag, they glow a dull red. The next morning, they don't glow at all, yet they feel warm when you hold your hand over them. The CMB has undergone a similar process, although spread over billions of years instead of hours.

This illustrates one of the basic laws of physics: Every object at a temperature above absolute zero radiates into its environment, with the type of radiation depending on the object's temperature. Your roaring campfire, for example, gives off visible light, with a lot of yellow — and a small amount of green and blue — wavelengths.

As the coals cool, the radiation slides to lower-energy (and longer-wavelength) red light. By morning, the cooling takes the radiation down below the visible range and into the infrared. This is the heat you still feel.

During the past 14 billion years or so, the universe itself has gone through a process similar to those coals in your fire. It started out bathed in high-energy gamma rays. As it expanded and cooled, the type of radiation slid to longer wavelengths — through visible light, infrared, and finally, down to microwave. The discovery of this



THE ELECTROMAGNETIC SPECTRUM shows the difference between high-energy gamma rays and low-energy microwaves. The universe's expansion stretched gamma-ray wavelengths from 10^{-12} meters to long, 0.2-centimeter microwaves in the CMB. *ASTRONOMY*: ROEN KELLY

so-called cosmic microwave background and a full understanding of its significance is one of the most fascinating tales in the history of cosmology.

Cosmic models

It may be hard to believe with today's scientific evidence, but not so long ago, scientists had serious doubts about the Big Bang theory. Everyone knew the universe is expanding, of course — Edwin Hubble had settled that in the 1930s. But a group of British astrophysicists suggested a picture of the universe quite different from the Big Bang.

Called the steady state model, the theory agreed with the observation of galaxies moving away from each other, but it said new matter (and eventually new galaxies) is created in the spaces left behind.

In the 1960s, this model was proposed as a serious alternative to the Big Bang, although few believed in it. A problem in deciding which theory was correct was that both the Big Bang and steady state models explained the one piece of observational evidence we had about the universe — galaxies are moving away from each other. Astronomers needed a new piece of data — a new observation — that would establish which theory was correct.

Signal in static

The missing puzzle piece came from an unexpected source. The early 1960s was when trans-Atlantic television transmissions started. The system — unbelievably primitive by modern standards — bounced TV signals off an orbiting mylar balloon, about 100 feet (30 meters) across.

Getting these signals through was such a technological feat at the time that a legend "Live from Europe" would appear at the bottom of the TV screen when they were shown.

Because scientists were pointing receivers at the sky to get a signal, they needed to know exactly what else was coming in from other sources — sources that interfered with the weak beam from the satellite. Two scientists at Bell Labs in New Jersey — Arno Penzias and Robert Wilson — worked to answer this question. Because TV signals are in the microwave part of the spectrum, the two took an old microwave antenna, pointed it at the sky, and began to survey what was out there.

They quickly ran into a problem. No matter which way they pointed their antenna, they found a faint whisper of microwaves raining down.

In the field of electronics, detecting a signal coming from every direction usually means there is a problem with the equipment circuitry. To Penzias and Wilson, the faint hiss was a red flag, an indication that they needed to check their apparatus for flaws.

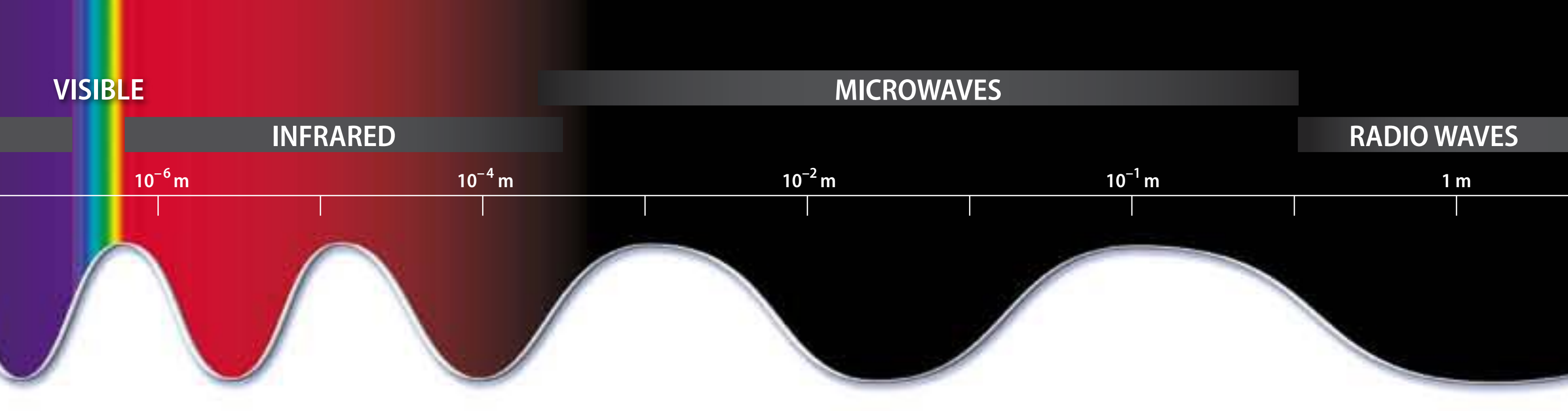
They evaluated one circuit after another. They even noted that pigeons had roosted in their antenna, coating the interior with a "white dielectric substance," which they removed. But the hiss persisted.

Then, a colleague mentioned a group of astrophysicists at Princeton University who were examining the consequences of the Big Bang. In fact, those astrophysicists had determined the cooling universe should be bathed in microwave radiation, which could be thought of as an echo of the Big Bang.

Observation becomes proof

The best way to understand this prediction is to refer back to the campfire example. This time, imagine you are watching it cool

WHILE SURFING THE RADIO, Robert Wilson (left) and Arno Penzias unexpectedly discovered the CMB with this horn-type antenna. This picture was taken in 1978, after they received their Nobel Prize. ASTRONOMICAL SOCIETY OF THE PACIFIC



from inside the coals. At the beginning, you would see visible light coming at you from all directions. As the campfire cools, the radiation slides to red, then to infrared, but it is always coming from every direction.

In the same way, the theorists argued, observers on Earth should see radiation raining down from all directions. As the universe cooled and expanded, the radiation dropped to long-wavelength microwaves. The faint hiss the observers couldn't get rid of was precisely the signal that should have been there. What had begun as a routine survey became a dazzling revelation about the cosmos. Penzias and Wilson shared the 1978 Nobel Prize in physics for their work.

The CMB discovery removed all doubts about the Big Bang and sent the steady state model to the dusty back room. During the next couple of decades, whatever controversy existed about the CMB centered on whether it is the kind of radiation we should expect from an object that has been cooling for 14 billion years.

A perfect fit

The laws of physics require that every object above absolute zero gives off radiation, and the lower the temperature, the longer the radiation wavelength. The laws say precisely how much of each type of radiation a body at a given temperature should emit. They also say an object radiates a range of wavelengths: a small amount of long- and short-wavelength radiation, with most of its energy radiated at a particular wavelength that depends on the object's temperature.

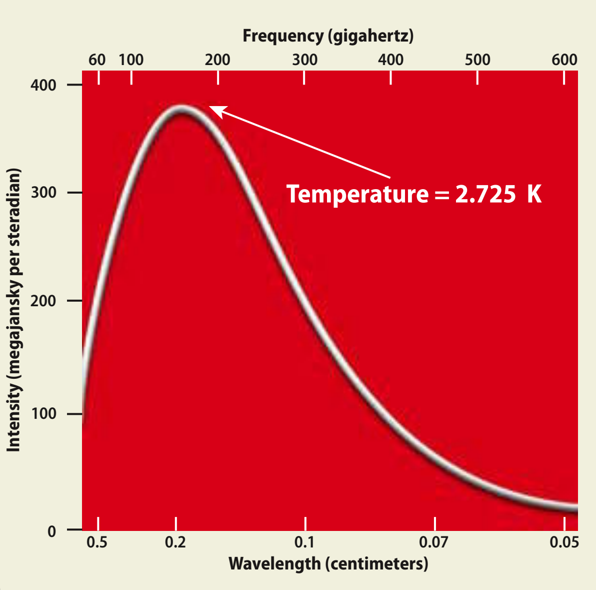
The Sun, for example, has an outer surface at about 5,800 kelvins, so it emits most of its radiation in the form of visible light. It also gives off small amounts of both radio and ultraviolet — the latter is obvious every time you get a sunburn. The curve that shows the amount of radiation at each frequency for a given object is called a blackbody curve (see "The universe's temperature," to right).

/// BLACKBODY RADIATION

THE UNIVERSE'S TEMPERATURE

Any object with a temperature above absolute zero radiates a range of energy. The energy radiated follows a spectral distribution curve — known as a blackbody curve. The curve is typically shown as intensity versus wavelength, and it peaks at a characteristic wavelength, which corresponds to a particular temperature.

The spectral distribution curve eventually led to the origins of quantum theory. When deriving the calculation, physicist Max Planck determined the energy emitted or absorbed must be in discrete packets — quanta, or photons. The blackbody curve is also known as the Planck radiation curve. — *Liz Kruesi*

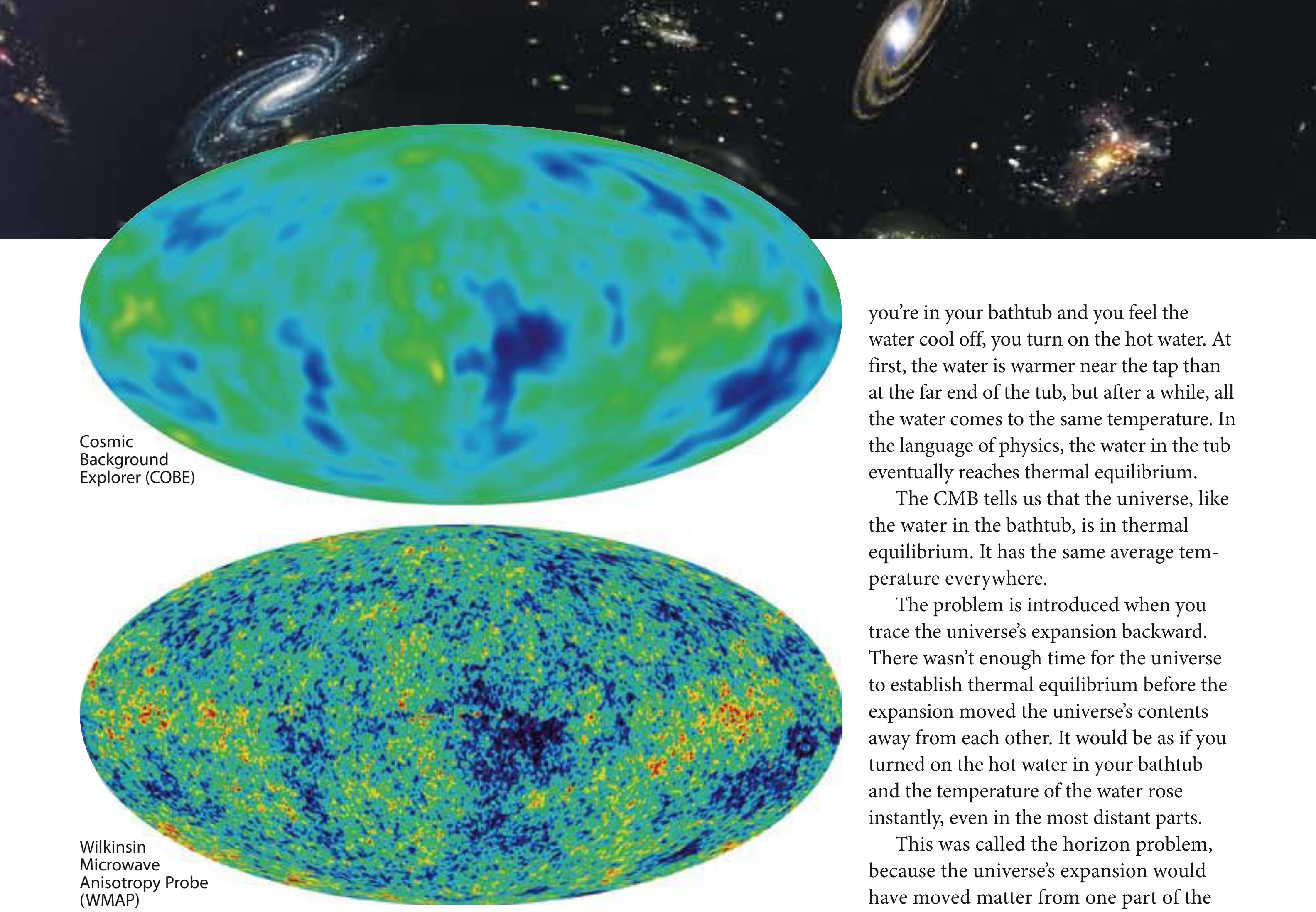


ASTRONOMY: ROEN KELLY, AFTER NASA/COBE

NASA'S COBE measured the CMB's spectral distribution and found it has a perfect blackbody curve — the best example found in nature. Its maximum-intensity peak, at roughly 0.2 centimeter, corresponds to a temperature of 2.725 K. Intensity is given as energy flux, jansky, per solid angle, steradian.

A ROARING CAMPFIRE gives off visible white light. As it cools, the emitted radiation slides to red, and eventually infrared, which is the heat you feel the following day. This is an example of a blackbody: an object that radiates energy, with the most prominent wavelength corresponding to a certain temperature.

ASTRONOMY: ROEN KELLY


Cosmic Background Explorer (COBE)
Wilkinsin Microwave Anisotropy Probe (WMAP)

THE ANGULAR RESOLUTION difference between COBE and WMAP is staggering. COBE was launched in 1989; its data was released in 1992. The scientific community was in awe at the sky maps COBE took, limited as they were by the spacecraft's low angular resolution (7°). WMAP followed in 2001, with its first data release in 2003. Its sky maps show far greater detail than COBE because the probe has an angular resolution of 0.3°, or 18'. NASA/WMAP SCIENCE TEAM

Earth's atmosphere absorbs some microwave wavelengths, so parts of the expected spectral curve were not visible to ground-based antennae. The search to fill in the gaps of the blackbody curve was postponed until the technology was ready, in 1989, when NASA's Cosmic Background Explorer (COBE) satellite was launched.

Sitting above Earth's obscuring atmosphere, COBE measured the radiation with unparalleled accuracy. When University of California at Berkeley astronomer George Smoot first presented the COBE data at a scientific meeting in 1992, the audience of sober, tweed-clad scientists burst into wild applause when the perfect blackbody curve was flashed on the screen.

James Trefil, *a member of* Astronomy*'s editorial board, is a professor of physics at George Mason University in Fairfax, Virginia.*

Answers raise more questions

The microwave radiation was exactly what it should have been for a universe that had cooled to an average temperature of 2.725 K above absolute zero. But there was another problem.

Although the microwaves fall on Earth from all directions, as expected, the radiation is the same no matter which direction we look. This is true to an accuracy of about one part in 100,000, which means that all parts of the universe, whether we look up, down, or sideways, are at the same temperature.

To understand why this poses a problem, think about another everyday experience. If you're in your bathtub and you feel the water cool off, you turn on the hot water. At first, the water is warmer near the tap than at the far end of the tub, but after a while, all the water comes to the same temperature. In the language of physics, the water in the tub eventually reaches thermal equilibrium.

The CMB tells us that the universe, like the water in the bathtub, is in thermal equilibrium. It has the same average temperature everywhere.

The problem is introduced when you trace the universe's expansion backward. There wasn't enough time for the universe to establish thermal equilibrium before the expansion moved the universe's contents away from each other. It would be as if you turned on the hot water in your bathtub and the temperature of the water rose instantly, even in the most distant parts.

This was called the horizon problem, because the universe's expansion would have moved matter from one part of the universe so much that, as seen by other parts, that matter would appear to have moved over the horizon. Different sections could not communicate with each other to establish thermal equilibrium. This problem — along with others — was resolved in the 1980s with the development of inflation theory (see "Seeing the dawn of time," *Astronomy*, August 2005, for more information).

> The CMB has given us new insights into both the beginning and the end of the universe.

According to inflation, the universe in its earliest stages was much smaller than you would expect if you do a backward extension of the expansion; the universe was smaller than a sub-atomic particle. In this small state, thermal equilibrium was easy to establish. Then there was a period

of very rapid expansion — called inflation — driven by forces that can be calculated from the theory of elementary particles. In this expansion, the universe grew to the size of a softball, and eventually to the universe we see today.

What those spots tell us

So the regularity of the background taught us one lesson about the early evolution of the universe, and the small differences — the ones that amount to one part in 100,000 — taught us another.

For the first 400,000 years or so, the universe was so hot that no atoms could form. If an electron attached to a nucleus, the next collision would knock it off.

Matter consisted of what physicists call a plasma — gas that is so hot it is ionized and has loose electrons and nuclei knocking around. (The Sun is mostly plasma, and there is a partial plasma in every operating fluorescent lightbulb.) Plasmas absorb radiation, which means light and other forms of radiation get trapped in them and are constantly absorbed and re-emitted. Astrophysicists say the universe was "opaque" during this time.

Once the universe was about 400,000 years old, it had cooled to the point that neutral atoms could form — electrons and nuclei combined. This moment is called "recombination" (even though there wasn't a previous "combination"). Atoms are largely transparent to radiation — which is why light can travel such long distances through Earth's atmosphere. After recombination, the radiation that was initially trapped in the universe's plasma was free to escape.

The microwave background is the high-energy photons that were released when atoms formed, and the photons have spent the last roughly 14 billion minus 400,000 years being stretched out into microwaves as the universe expanded.

This is why the seemingly insignificant differences (scientists call them "anisotropies") in the CMB are so important. Places where matter was starting to clump together would have been at a slightly higher temperature than the surroundings, and we should be able to see that difference by looking at temperature differences in the CMB's spots.

The early concentrations of matter served as the points where matter — and eventually galaxies — condensed. Because of this, they often are called "seeds," although I prefer the more poetic "ripples at the beginning of time."

Ripples were first seen in data from the COBE satellite. So important is this information that in 2001 another satellite — the Wilkinson Microwave Anisotropy Probe (WMAP) — was launched with the specific mission of measuring the CMB's spots to unparalleled accuracy. The comparison between COBE and WMAP is equivalent to putting on glasses to read the fine print in a document.

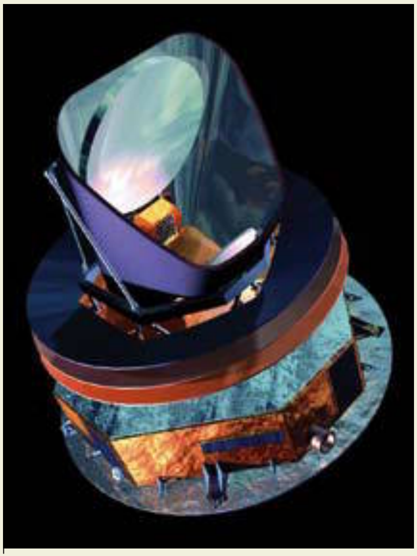
Forty years later

The detailed measurements of the CMB provided by many sources, including WMAP, have given astronomers precise information about our universe. We can now say with 99-percent certainty that the universe is 13.7 billion years old, and that the release of radiation from the plasma — the moment of last scattering — took place 379,000 years after the Big Bang.

WMAP also provides input into our current understanding that the universe is made of about 4-percent ordinary matter, 23-percent dark matter, and 73-percent dark energy. It was, in fact, corroborating data from WMAP that made scientists so willing to accept the notion that almost three-quarters of the universe is in the form of something called dark energy — something whose composition we still have to discover, but which will ultimately govern the fate of the universe.

The CMB has given us new insights into both the beginning and the end of the universe — not bad for an observation that started out as a calibration measurement designed to improve TV reception. ▲

/// CONTINUING THE QUEST



ESA/MEDIALAB

THE THIRD-GENERATION CMB PROBE, Planck Surveyor, will provide astronomers with even more detail about the composition and fate of the universe.

NEXT UP FOR THE CHALLENGE

In February 2007, the European Space Agency (ESA) will launch the third-generation CMB probe: Planck Surveyor. Compared to WMAP, Planck has roughly twice the angular resolution — 10' v rHus WMAP's 1.8

Planck Surveyor involves crucial science because it ?ill observe a wider frequency range than COBE or WMAP. Whereas WMAP covered the frequencies aom 3 to 94 GHz, Planck ill reach fa pDst that range, to ve 30 to 857 GHz. This will allow Planck to improve on WMAP's measurement by separatOnN foreground signals from CMB signals and by seeing 10 te es the frequency range WMct s w.

With the increased seesiti te ls ck will provide information in tho un erse's fundamental parameters — including spatial curvtt/re and expansion — in addition to measureng ructure size within the CMB.

Th tfirst Planck a a release mal be in late 010.— *L. K.*

The return of cosmic

Infinitely long, exceedingly thin, and unimaginably dense strands of primordial matter may wind their way through the universe. /// BY STEVE NADIS

Cosmic strings have led a checkered past: popular in the 1980s, denounced in the 1990s. Now, theoretical revisions supporv the idea that ultradense strands of matter could be the “seeds⌧ for galaxy formation.

Even Edward Witten of the Institute for Advanced Study, widely recognized as one of the world’s greatest theoretical physicists, now believes “strings of different sizes and kinds probably exist” — despite/the fact that, 20 years ago, Witten argued convincingly none was to be found. So, why are scientists now getting wound up about cosmic strings?

Much of the impetus comes from revisions to string theory, which describes fundamental forces and particles as tiny, string-like loops of energy. Current version of the theor5 how strings — the basic units of energy and matter — can reach a/tronomical sizes.

These strings, argues Joseph Polchinski from the University of California, Santa Barbara, would have been produced after inflation, which otherwise would dilute them to oblivion. Reformulated cosmic strings are stable over the age of the universe and less massive than the strings Witten and others contemplated in the 1980s. This means their influence on the universe would be less dramatic than previously thought, so they can’t be ruled out by recent observations.

Defects in space

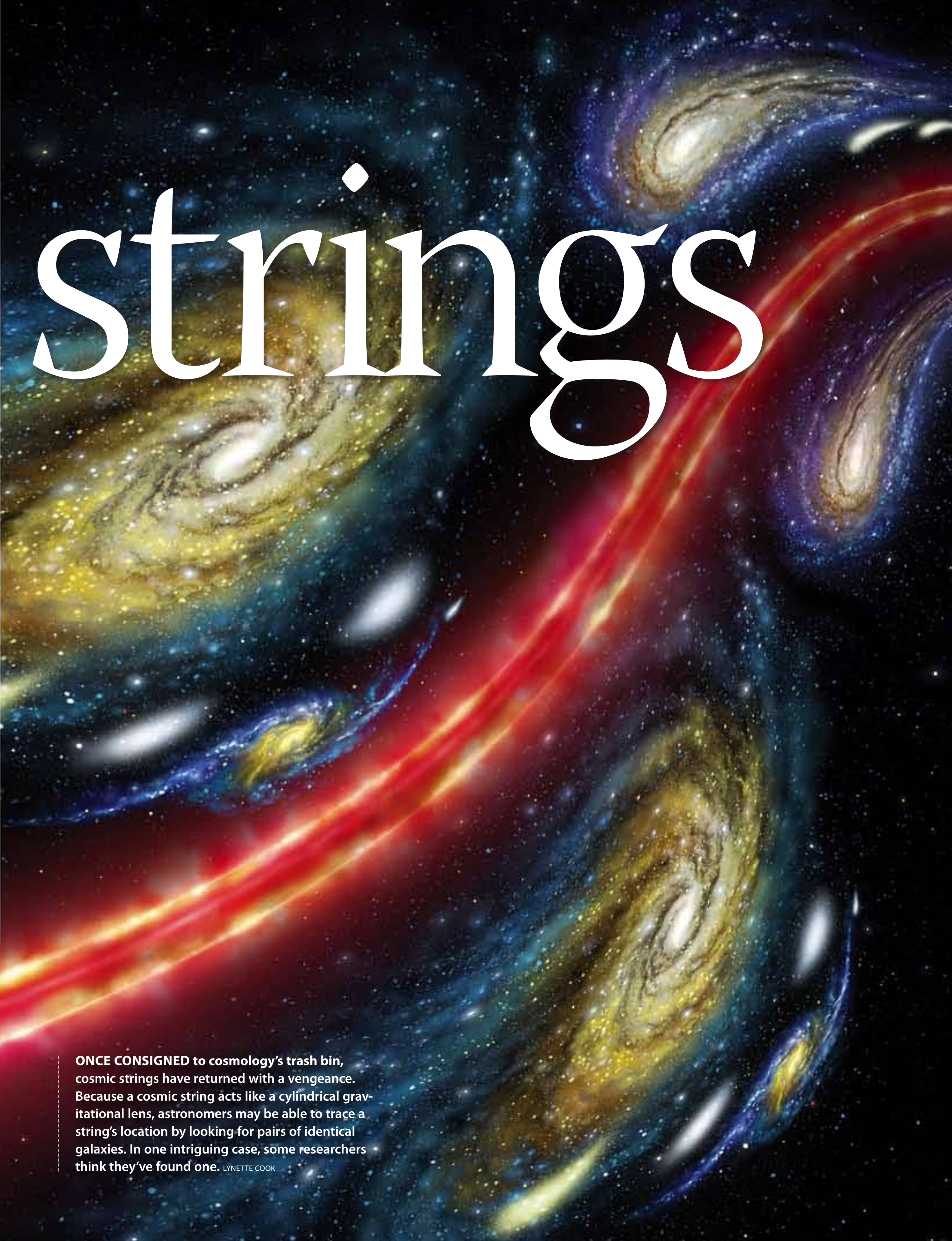
Witten concedes Polchinski and his colleagues deftly address the difficulties he raised, yet one question remains: Can we detect cosmic strings?

Maybe. Two research teams report evidence for cosmic strings in different parts of the sky. While these claims have yet to be either verified or refuted, they have “breathed new life into this field,” says Alexander Vilenkin of Tufts University, who in the 1980s first suggested cosmic strings could trigger galaxy formation.

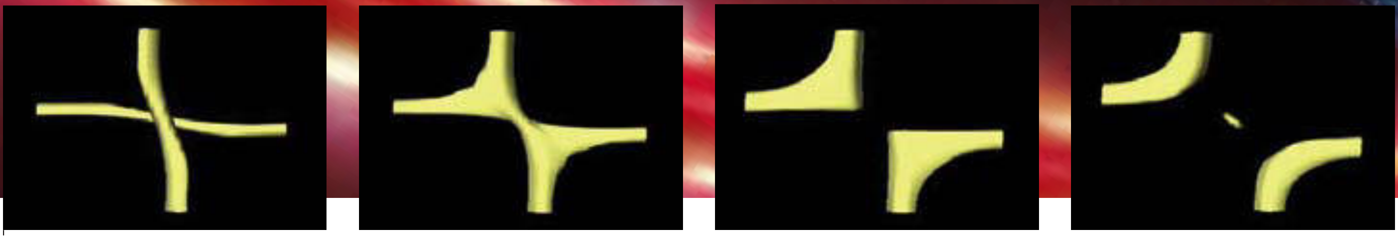
Cosmic strings are second only to black holes in the astrophysicist’s pantheon of weird objects. They are narrow, ultradense filaments formed during a phase transition — called inflation — within the first microsecond of cosmic history. Just as cracks can appear in ice as water changes from liquid to solid, the universe could hav⌧ de e⌧ ped topologic⌧ a defect as it in lraed Linear defects would have foomed a⌧ j nctures where⌧ iffer⌧ n areas undergoing the transition ran into each other, leaving b hi d⌧ sle⌧ ⌧ ⌧ r th⌧ eaU of u converted material forever trapped in a primorsiaa state.

Cosmic strings, the theory says, emerged ro⌧ qhis phase trans tio in C sp gh⌧ ti-li⌧ e ta ⌧ L. Indiv⌧ dual threads move at significant fractions of the speed of

strings



ONCE CONSIGNED to cosmology's trash bin, cosmic strings have returned with a vengeance. Because a cosmic string acts like a cylindrical gravitational lens, astronomers may be able to trace a string's location by looking for pairs of identical galaxies. In one intriguing case, some researchers think they've found one. LYNETTE COOK



WHEN STRINGS COLLIDE, they can exchange pieces and form a free-floating loop. In this computer simulation, two strings approach one another at half the speed of light, emitting radiation — usually gravitational waves. A new loop forms in the collision's aftermath. R. BATTYE AND E. P. SHELLARD, UNIVERSITY OF CAMBRIDGE

light. They're either long and curvy, with a complex assortment of wiggles, or fragmented into smaller loops that resemble taut rubber bands.

Although thinner than subatomic particles, cosmic strings are boundless in length, stretched ᴅcosmic expansion across the ⌧ niv⌧ rse. [hey are physically characterized by their mass per unit length, or tension, a parameter that reflects thea⌧ gryvita al heft. ah⌧ l near deosity can reach incredibly high values — about 1 million metric megatons per centimeter for strings formed at the so-called grand unification energies (10^{16} billion electron volts and higher), corresponding to a time when all four fundamental forces in nature were combined as one. "Neutron stars are among the densest compact objects we know of, but even if we squeezed one billion neutron stars into the size of an electron, we would still hardly reach the matter-energy density characteristic of grand unified cosmic strings," notes Alejandro Gangui, and astronomers at the University of Buenos Aires.

Steve Nadis *is a science writer and frequent* Astronomy *contributor who lives in Cambridge, Massachusetts.*

String lenses?

Objects this massive must have a phenomenal gravitational influence. If a string ran between the Milky Way and another galaxy, light from that galaxy would go around the string symmetrically, producing two identical images near each other in the sky. "Normally you'd expect three images, if lensing is due to a galaxy," says Vilenkin, with some light traveling straight through the lensing galaxy and other rays traveling around either side. Light can't go through a string because the string's diameter is much smaller than the light's wavelength, so strings produce only two images.

A Russian-Italian group led by Mikhail Sazhin of Moscow State University has recently discovered remarkably similar double images of a galaxy named CSL-1 in the constellation Corvus. Both images have the same redshift (0.46), and their spectra are "identical at a 99.96-percent confidence level," claims Giuseppe Longo, a collaborator from Federico II University in Naples. The data "can be interpreted either as the chance alignment of two identical galaxies," the Italy team says, "or as the first case of lensing by a cosmic string."

Vilenkin considers this observation an "intriguing case that a string could explain quite naturally." Thomas Kibble of Imperial College in London, whose 1976 paper sparked interest in cosmic strings, thinks there's a reasonable chance a cosmic string is responsible for the images. "I won't bet heavily on it, but I might make a small wager," he says.

There's nothing uncommon about finding pairs of galaxies in the sky, counters Harvard University cosmologist Abraham Loeb: "Andromeda and the Milky Way are close together, and to a distant observer, they might look very similar."

There's no way to exclude the possibility of two similar galaxies sitting next to each other by coincidence, agrees Case Western Reserve physicist Tanmay Vachaspati. If there is a cosmic string there, he says, the number of double images in its vicinity should exceed that expected by chance. Sure enough, Sazhin and colleagues found 11 other pairs in the area around CSL-1. Their next step is to obtain more detailed spectroscopy with the European Southern Observatory's Very Large Telescope in Chile to find out how similar these paired galaxies really are.

The team also is pursuing another, possibly more definitive, test: trying to determine

/// STRINGS OBSERVED: EXHIBIT A

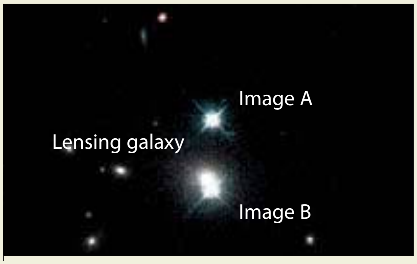
THE DOUBLE QUASAR

In 1979, radio astronomers found the Double Quasar, Q0957+561A/B, in Ursa Major. A foreground galaxy cluster creates two identical images of the same quasar separated by 5.7". This was the first confirmed gravitational lens, and it has played a pivotal role in astronomers' understanding of the phenomenon.

In August 2004, a team led by Rudolph Schild of the Harvard-Smithsonian Center for Astrophysics detected concurrent brightness changes in both quasar images. Looking at data from 1994 and 1995, the astronomers found several oscillations with a period of about 80 days. If these changes have a common origin, the astronomers reasoned, they must be due to a large object very close to us.

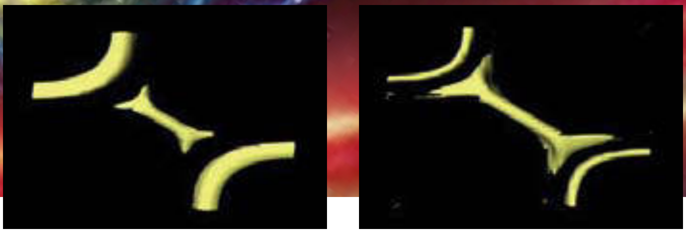
Schild and colleagues calculated a binary pair of 78-solar-mass stars within 4 light-years of Earth could cause the effect. But the idea that such stars would have gone unnoticed seems unlikely — and the mass requirement only increases for more distant objects.

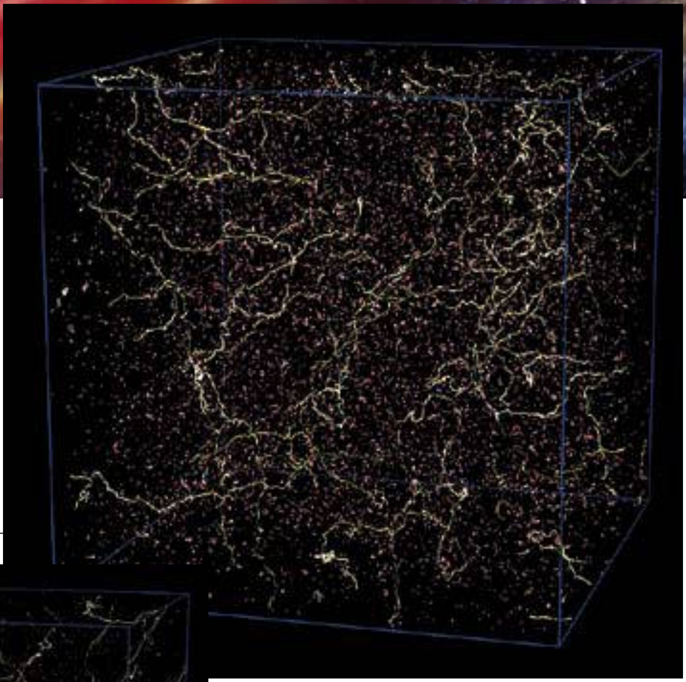
On the other hand, a cosmic string loop within our galaxy could produce the fast oscillations. A period of 80 days implies a loop about 160 light-days long. Trucking through our galaxy at a substantial fraction of light-speed, the loop might spend only a year in the line of sight between Earth and the Double Quasar. — *Francis Reddy*



NOAO/AURA/NSF

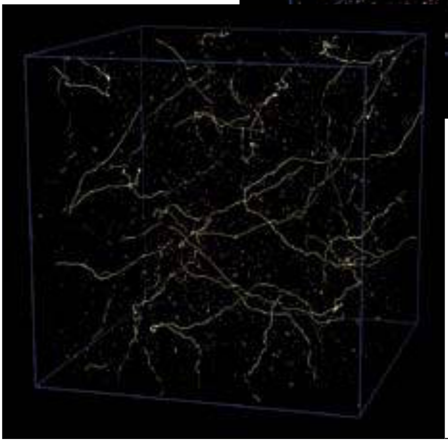
A MASSIVE GALAXY splits the distant quasar's light and forms two images.





B. ALLE AND E⊠ o. SHELLARD, ⊠ IvERSITY⊠ F⊠ CAMBRIDGE

▶WHEN COSMOLOGISTS MODEL cosmic-string evolution, their main goal is to predict how a number of averaged properties — such as the speed, separation, and number of strings in a given volume — change over time. The simulation at right shows strings when the universe was young and dominated by radiation, in its first 10,000 years. Space is filled with cosmic strings. Long strings have many "wiggles," and there's a high density of small string loops.



B. ALLEN A⊠ D E. S ELbA⊠ p, U VERSITY OF CAMBRIDGE

◀A SNAPSHOT OF A STRING NETWORK in the universe's matter-dominated era — after the first 10,000 years — shows a much-lower density of both long strings and loops. Also, long strings display fewer wiggles. Simulations of string evolution help cosmologists test how effectively cosmic strings can trigger galaxy formation.

whether the images are truly identical or just vaguely similar. Lensing by a galaxy leads to distorted images that differ in size and shape — light passing far from the galaxy appears to bend less than light passing nearby. A cosmic string bends light by the same amount no matter how far light passes from it. So, if the string is straight, it will produce two undistorted images with a sharp edge between them — like a pair of snapshots sitting side by side. "No other phenomenon to our knowledge can produce such a morphology," says Longo. If the astronomers see a sharp edge with the Hubble Space Telescope, the only instrument with sufficient angular resolution, they'll be confident it is a string.

Meanwhile, there may be another cosmic string floating around our galactic neighborhood. The idea — postulated by Rudolph Schild of the Harvard-Smithsonian Center for Astrophysics and three colleagues from Kiev Observatory — is that brightness oscillations in a well-known quasar, Q0957+561A/B, are explained most plausibly by a cosmic string loop located within our galaxy's halo.

> If we squeezed a billion neutron stars into the size of an electron, we still wouldn't reach the densities of cosmic s⊠ eing .

Monitored since 1979, Q0957 is the first known example of gravitational lensing. A distant galaxy serves as the lens, which creates two images of the quasar that show the same brightness oscillations, although separated by a 1.1-year time delay. But during a 400-day period in 1994 and 1995, the brightness of the two images oscillated in synch, with no time lag. Schild and company attribute this anomaly to a gravitational lens. They picture a rotating string loop that flew across our line of sight in 1994 and 1995, simultaneously affecting both quasar images, before disappearing from view. More conventional explanations, such as lensing by a double-star system, already have been ruled out.

Fermilab physicist Mark Jackson finds the explanation interesting, but inconclusive. "We need a more sophisticated [cosmic string] model to see if it holds together," he says.

Finding a nearby cosmic string — estimated at 10,000 light-years away — is highly unlikely, although not impossible, says Vachaspati. Computer simulations suggest long strings should be spaced roughly 325 million light-years apart. But for now, he doesn't have a better explanation for the synchronous blinking.

What's needed, says Tufts physicist Ken Olum, is a statistical analysis that would reveal whether the unexpected brightness fluctuations are, in fact, real. Schild concurs and is working on that problem with Bell Labs mathematician Dave Thomson.

Confirmation of just one lensing event by a cosmic string would be momentous. Researchers can estimate the string's tension by determining the extent to which light is bent. The tension, in turn, reflects the energy scale of the primordial phase transition that gave rise to the string. Knowing this energy scale would help cosmologists limit possible models of the early universe.

With one lensed pair in hand, investigators will try to trace out the string's path in the sky. "The string will cut through the middle of the two objects, but the angle is hard to determine," explains Vachaspati. Most likely, the search will be

hit-or-miss at first, as astronomers scour the surrounding area. But as more pairs are found, the path of the string should become clearer. "You can search in optical, infrared, radio, whatever you like," says University of California, Berkeley, astrophysicist George Smoot. "A cosmic string would treat all light alike."

Once there's an unambiguous case of lensing by a string, Polchinski adds, "We'll want to do a systematic search." He predicts the science will move quickly after astronomers verify the first discovery. "We're likely to go from one event to 1,000 events in 10 years." While this survey proceeds, people will continue to invent new ways of looking for strings.

The cosmic microwave background (CMB), for example, offers another avenue. Cornell University physicist Henry Tye suggests cosmic strings may be responsible for 10 percent of the temperature differences (and related density fluctuations) in the CMB, thereby contributing to the creation of galaxies and galaxy clusters. Smoot says he and other researchers are waiting for better data to pin down what, if any, role strings played in structure formation.

Even if a supporting role is ultimately ruled out, cosmic strings should still create a linear discontinuity in the CMB — two regions with slightly different temperatures. This temperature difference stems from the Doppler effect: Photons on one side of the fast-moving string get pushed, which gives them a higher frequency and temperature than photons on the other side that are not pushed. Although this effect has not yet been documented in CMB data, it may be detectable, says Tye, depending on how fast the string is moving and its tension or mass.

Looking with LISA

Long threads of superdense material moving near the speed of light should throw off lots of gravitational radiation — an effect predicted by Albert Einstein almost 90 years ago. The Laser Interferometer Gravitational Wave Observatories (LIGO) in Louisiana and Washington might be able to detect such a disturbance. Vilenkin, who first considered gravitational radiation from strings in 1982, says, "This may be the only source of gravitational waves LIGO could detect."

The most visible gravitational signal would be produced by a cusp — a transient spike that forms when wiggles traveling along a cosmic string in opposite directions momentarily meet. As the cusp straightens itself out, its tip moves at the speed of light. "Like the crack of a whip, a great deal of energy is concentrated in the tip," Polchinski notes, "so it emits an intense beam of gravitational waves in the direction of its motion."

Cusps are the easiest thing LIGO could spot, says LIGO team member Xavier Siemens of the University of Wisconsin, Milwaukee. Such a signal is potentially within reach of the current LIGO, says Siemens, and it should be even more prominent when the "advanced" version comes online in a few years. With its greater sensitivity, the Laser Interferometer Space Antenna (LISA), due to be launched next decade, would have an even better chance of intercepting a cusp signal.

Because a cosmic string is a piece of the universe from a more energetic state, it provides a unique view of the physics that prevailed when it was created. "Cosmic strings might actually provide the best observational

/// STRINGS OBSERVED: EXHIBIT B

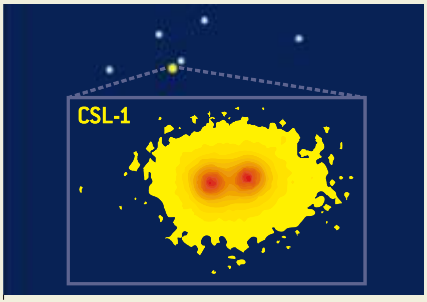
CAPODIMONTE STERNBERG LENS CANDIDATE 1 (CSL-1)

Images produced by garden-variety gravitational lenses — foreground galaxies or galaxy clusters — typically come in odd numbers and differ significantly in brightness. Cosmic strings should act as cylindrical gravitational lenses, creating nearly identical double images of any sources behind the strings.

In 2003, collaboration between Capodimonte Observatory in Naples, Italy, and Sternberg Astronomical Institute at Moscow State University turned up a close pair of seemingly similar elliptical galaxies in Corvus. Now known as Capodimonte Sternberg Lens candidate 1 (CSL-1), the galaxies appear to be twins separated by 2". If the pairing is a coincidence, it's a remarkable one, and there's no sign of a giant foreground galaxy that might serve as a traditional lens. A team led by Moscow State's Mikhail Sazhin concluded the best explanation was lensing by a cosmic string.

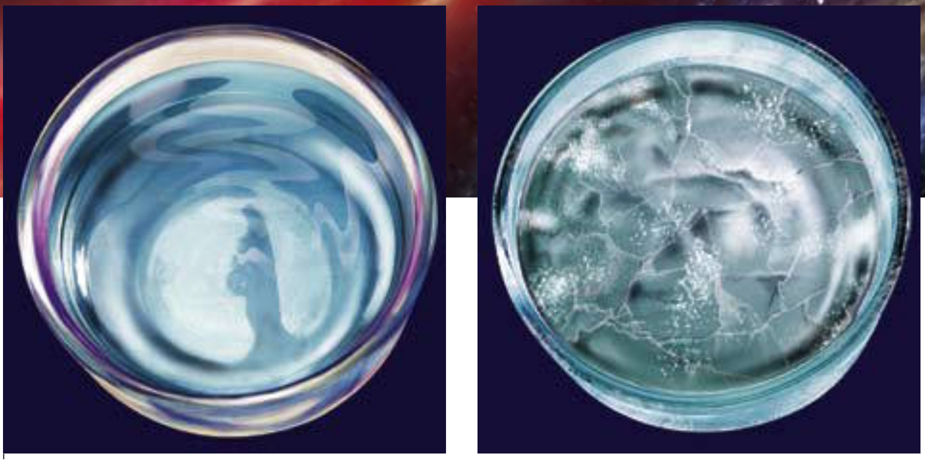
The same team then searched for pairs among the roughly 2,200 galaxies near CSL-1. The astronomers found 11 pairs that, on the basis of separation and color similarity, could be lensed galaxies. Conventional lensing, they argued, should produce no more than two pairs in the same field of view, while a cosmic string could produce as many as 200, depending on its precise configuration.

A cosmic string should leave its distorting imprint on the CMB. Using Wilkinson Microwave Anisotropy Probe data, astronomers Amy Lo and Ned Wright of the University of California, Los Angeles, searched for and found an edge in the microwave background at CSL-1. But if the edge is real, a cosmic string responsible for it must be moving at more than 96 percent of lightspeed — unlikely, they conclude. Critical tests of CSL-1 must await detailed data from facilities now being built, such as the European Space Agency's Planck probe. — *F. R.*



ASTRONOMY: JAY SMITH

CSL-1 (inset) and other paired galaxies (light blue) may trace a cosmic string.



COSMIC STRINGS FORMED as defects in space-time when the universe cooled. The process is analogous to cracks that form as water freezes to ice.

ASTRONOMY: JAY SMITH

window into fundamental string theory," notes Imperial College's Thomas Kibble, while also offering the chance to test the predictions of string-based inflation models.

Most of those models are now based on "brane inflation," an idea advanced by Tye and New York University physicist Gia Dvali in 1999. Inflation, Tye and Dvali suggest, ensued when two stacks of three-dimensional membranes, or branes, drifted toward each other in higher dimensions due to gravity's tug. In this scenario, inflation ended when the branes collided and melted, creating the Big Bang.

Polchinski likes the Dvali-Tye scenario because it shows where the energy that drives inflation comes from. "Brane inflation offers a natural geometric picture that automatically leads to the right phase transition that produces cosmic strings," he says.

Two kinds of cosmic strings were created during that phase transition, according to Tye: F-strings, the basic building blocks of string theory that make up electrons and protons, stretched across the entire sky; and D-branes, which assume various forms, including one-dimensional strings. "Brane inflation gives you all you need for cosmic strings to survive and be observable," says Dvali. What's more, adds Tye, string tensions predicted by brane inflation are compatible with the latest observations.

How would these cosmic strings differ from the "old-fashioned" ones discussed by Kibble and Vilenkin in the 1970s and 1980s, before string theory took off? To simplify the terminology, some researchers use the term *cosmic superstrings* to distinguish new string-theory versions from the cosmic strings of old. "Every idea that existed for conventional cosmic strings has a counterpart in string theory," says Fermilab's Mark Jackson. But the concept is much richer because it predicts a greater variety of superstrings.

Superstrings travel in different dimensions and have a range of tensions, whereas scientists expect traditional cosmic strings have uniform tensions. In string theory, three different cosmic superstrings can join to form a junction, and each would have a different tension that fits a specific relationship, says Jackson. The old kind of cosmic strings don't form junctions.

Another big difference between cosmic strings and superstrings relates to what happens when they collide. Cosmic strings almost invariably reconnect, meaning the two strings intersect to form an X. The X, in turn, breaks off to form two Vs. The Vs become vibrating loops that decay through gravitational radiation and eventually disappear. Cosmic superstrings, by contrast, don't always reconnect. They may intersect, say, 10 percent of the time, but can otherwise pass through each other without crossing because they move in higher dimensions.

"This will be a window on physics at energies up to a trillion times higher than particle accelerators can reach."
— Joseph Polchinski

The difference should have significant observational consequences. There should be more long cosmic superstrings around than cosmic strings simply because superstrings cut themselves up less often. "By looking at the sky and counting the number of long strings, we may be able to tell whether they are ordinary cosmic strings or superstrings," says Vilenkin.

A cosmic-string "census" would be very helpful in this regard, but for the time being, such an effort will have to be accomplished with a computer rather than a telescope. Simulating the distribution of cosmic strings is exceedingly difficult, says Polchinski, in part because of the dynamic range: from loops on the light-year scale to long strings extending 10 billion light-years or more. Plus, the system itself is intrinsically complex to model, with long strings and smaller loops moving, crossing, and oscillating in nonlinear ways — all of which occur in an expanding universe. Although high-resolution computer simulations could help scientists predict how strings are arranged in the sky, it may take a credible detection before researchers are ready to embark on such a project.

Vilenkin, along with Tufts colleagues Ken Olum and Vitaly Vanchurin, is developing a simulation to determine, among other things, the curviness of strings and the number and size of their wiggles and loops — all of which affect the gravitational waves likely to be produced. A major undertaking, it could provide insights on cosmic-string evolution, which remains poorly understood.

Knowledge gained from simulations, theory, and observations offers a potentially large payoff. "This will be a window on physics at energies up to a trillion times higher than particle accelerators can reach," Polchinski says. "We're really at the dawn of a new era of science."

And cosmic strings, which not long ago seemed destined for the rubbish bin of physics, are now at the center of things. Well, maybe not exactly at the center: They may be lurking, instead, at our galaxy's edge. A

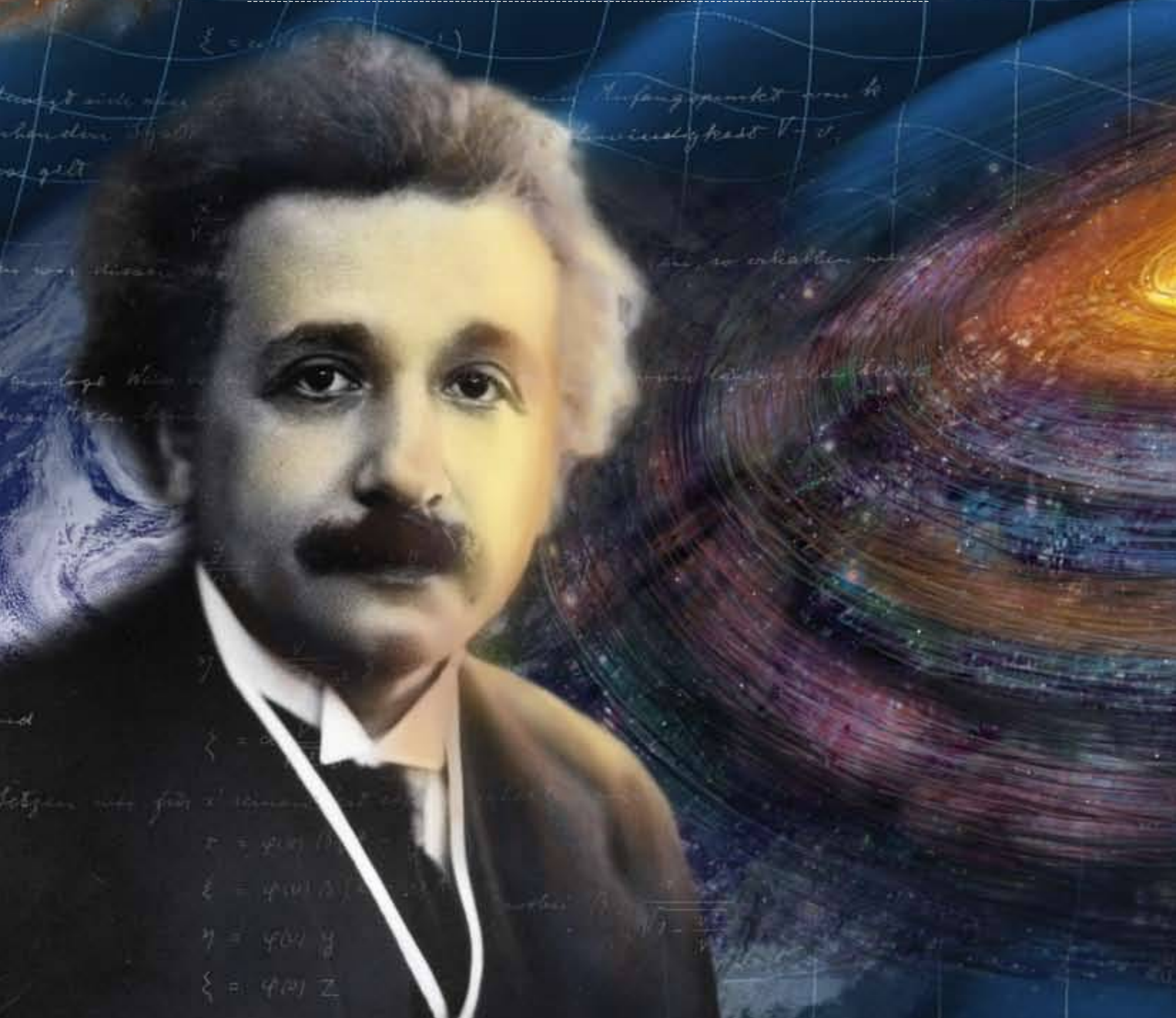
ONLINE EXTRA See cosmic string movies from a a computer named COSMOS at www.astronomy.com/toc

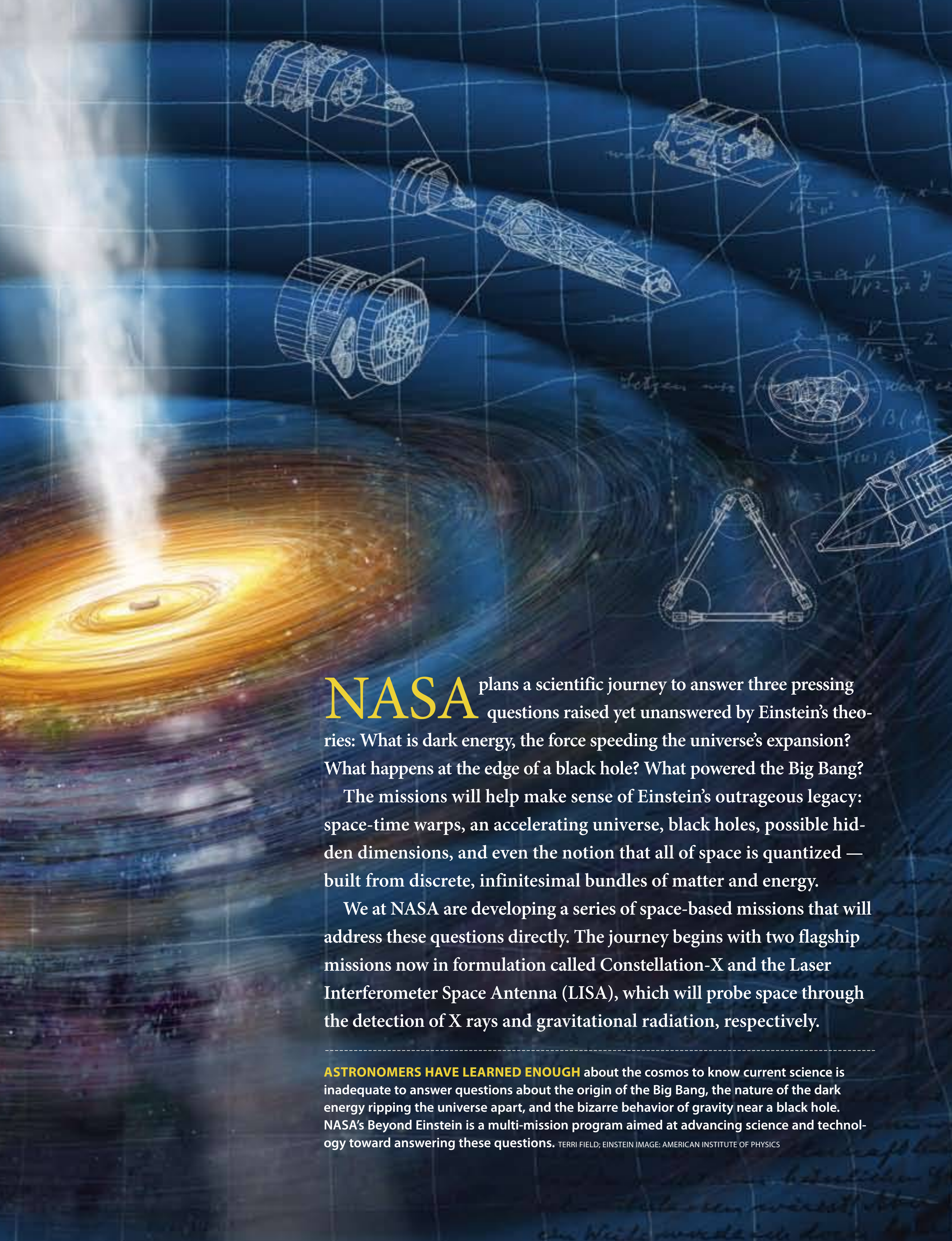
SPECIAL COSMOLOGY ISSUE

Beyond Einstein

NASA's new spacecraft will attack thorny questions concerning the nature of dark energy, black holes, and the Big Bang. Here's a sneak peek at what's to come.

/// BY ANNE KINNEY, NICHOLAS WHITE, AND CHRISTOPHER WANJEK





NASA plans a scientific journey to answer three pressing questions raised yet unanswered by Einstein's theories: What is dark energy, the force speeding the universe's expansion? What happens at the edge of a black hole? What powered the Big Bang?

The missions will help make sense of Einstein's outrageous legacy: space-time warps, an accelerating universe, black holes, possible hidden dimensions, and even the notion that all of space is quantized — built from discrete, infinitesimal bundles of matter and energy.

We at NASA are developing a series of space-based missions that will address these questions directly. The journey begins with two flagship missions now in formulation called Constellation-X and the Laser Interferometer Space Antenna (LISA), which will probe space through the detection of X rays and gravitational radiation, respectively.

ASTRONOMERS HAVE LEARNED ENOUGH about the cosmos to know current science is inadequate to answer questions about the origin of the Big Bang, the nature of the dark energy ripping the universe apart, and the bizarre behavior of gravity near a black hole. NASA's Beyond Einstein is a multi-mission program aimed at advancing science and technology toward answering these questions. TERRI FIELD; EINSTEIN IMAGE: AMERICAN INSTITUTE OF PHYSICS

THE EUROPEAN SPACE AGENCY'S XMM-NEWTON X-ray telescope has recorded rapid changes and broadened spectral lines in active galaxies that astronomers think likely arise from within a black-hole accretion disk. Iron lines from the Seyfert galaxy MCG-6-30-15, shown in this Hubble Space Telescope view, are so skewed, astronomers say, they must be coming from regions moving near 224 million mph (360 million km/h). According to the University of Maryland's Chris Reynolds, a rapidly rotating black hole is the only explanation for these phenomena if astronomers assume general relativity is valid. NASA/STScI

Complementing them will be three smaller, focused missions to study black holes, the Big Bang, and dark energy. The scientific and technological advances gained along the way will lead us to the ultimate goal of two bold Einstein vision missions that will image a black hole and the Big Bang itself.

We call this multi-mission endeavor "Beyond Einstein," because it should generate discoveries that will lead to a better understanding of fundamental physics beyond the theories that Einstein, his colleagues, and their predecessors developed.

Going back 100 years

In March 1905, a few days after Einstein's 26th birthday, the first of his five scientific papers that year arrived on the desk of the editor at the physics publication *Annalen der Physik*. Einstein's paper proposed that light is composed of energy particles, which would soon be known as photons.

The theory, called the photoelectric effect, bluntly challenged the ingrained perception that light travels in waves. Two more papers followed in April and May, helping seal the case for the existence of atoms, a new and controversial topic at the time. The April document, which earned Einstein his doctoral degree, showed how to count the number and size of molecules in a solution; the May paper explained the Brownian motion phenomenon.

Apparently not shy to rattle the establishment, Einstein took on Isaac Newton in June. In what would become known as his theory of special relativity, Einstein said the speed of light is a fundamental constant and that space and time are relative, depending on one's frame of reference.

Newton's laws of motion, golden for nearly 200 years, were only an approximation, valid at "everyday" speeds but not when approaching that of light. In September, Einstein tweaked his theory and offered one of the most famous equations of all time, $E=mc^2$. Thus, special relativity implied matter and energy are interchangeable.

Einstein was just getting warmed up. In the following years, he recognized that gravity and acceleration are one and the same, and that light exists both as particles and waves. Einstein labored to apply his relativity theory to a new gravity theory, again challenging Newton and his gravity law that was carved in stone.

By the end of 1915, Einstein published his theory of general relativity, which described gravity as a result of mass and energy distorting space-time, a four-dimensional concept commonly referred to as the fabric of space itself. Einstein's greatest contributions to science continued at full speed into the 1920s, when he and Satyendra Nath Bose predicted a new state of matter — called the Bose-Einstein condensate — that should exist at temperatures fractions of a degree above absolute zero.

All told, Einstein had a 20-year run that transformed our understanding of time, energy, and matter. Much of what he could not answer — and struggled with until the day he died in 1956 — remains unanswered today. Questions about dark energy, black holes, the Big Bang, and the nature of gravity have come to define the cutting edge of science. Probing these issues may lead to Einstein's lifelong goal of combining relativity with quantum mechanics into a unified theory of everything.

Unanswered questions

Einstein's theories on space and time led to a startling set of predictions that he himself could not believe: The universe is expanding from a Big Bang. Black holes cause space to buckle and bring time to a halt. A mysterious force is pulling space apart, sending galaxies forever beyond the edge of the visible universe. One by one, these predictions have been verified — the last one as recently as 1998.

> Much of what Einstein could not answer remains unanswered today.

Unfortunately, Einstein's theories are silent on the cause of the Big Bang and the detailed physics behind black holes and dark energy. So, these three areas become focal points we must probe. By thoroughly examining the Big Bang, black holes, and dark energy, we will expose flaws in our current understanding of nature that will enable us to move to a new era of physics.

Such an approach is not without precedent. At the beginning of the 20th century, Einstein hammered away at flaws in

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Anne Kinney *is the director of NASA's Astronomy and Physics Division, which conducts research into astronomy and fundamental physics.* **Nicholas White** *is the director of NASA's Exploration of the Universe Division, in which* **Christopher Wanjek** *serves as a science writer.*

Newton's laws of motion and James Maxwell's theory that light propagates through an all-pervasive ether. At the beginning of the 21st century, we too are faced with major incongruities. Quantum mechanics and general relativity have served us well, but something is clearly wrong with both theories.

For example, neutrinos shouldn't have mass, but they do. Predicted particles remain elusive. Perhaps the biggest flaw: Gravity remains an oddball force that refuses to be quantized, like light (photons) and strong subatomic forces (gluons). Indeed, gravity is at the nexus of understanding the Big Bang, black holes, and dark energy.

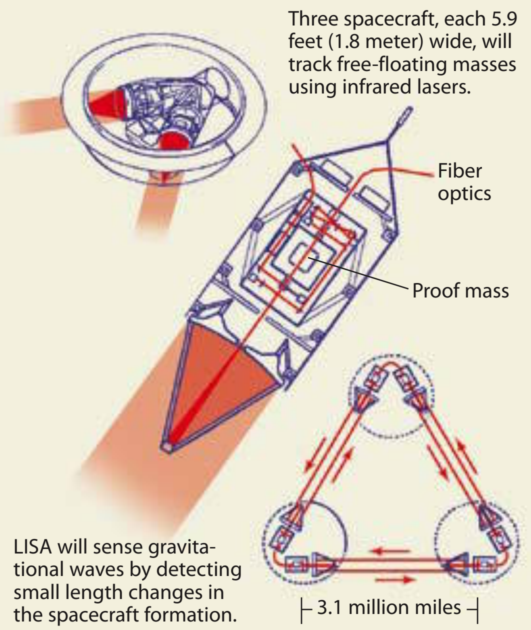
In pursuit of unification

As University of Chicago cosmologist David Schramm wrote in 1998, "The study of the very large (cosmology) and the study of the very small (elementary particles) is coming together." His vision of uniting general relativity with quantum mechanics into a unified theory of everything appears throughout the 2003 National Academy of Science report, *Eleven Science Questions for the New Century*, informally known as the Turner Report.

In 2004, the U.S. Office of Science and Technology Policy responded to the Turner Report with a pledge to combine efforts from NASA, the National Science Foundation (NSF), and the Department of Energy. NASA's Beyond Einstein program captures much of what the report proposes — solving the mysteries of dark energy, dark matter, black holes, extra dimensions, neutrinos, and more. It is, in essence, a series of missions linked by new technologies and complementary approaches to shared science goals.

Beyond Einstein began with funding in NASA's 2004 budget and represents a combined effort of the particle physics and astronomy communities. NASA will search for answers in space, while the other agencies will focus mainly on ground-based and balloon-based instruments and observatories, although there's exciting camaraderie. Together, by the close of the next decade, we hope to have answers to some of the most profound questions of our day.

Laser Interferometer Space Antenna (LISA)



Three spacecraft, each 5.9 feet (1.8 meter) wide, will track free-floating masses using infrared lasers.

LISA will sense gravitational waves by detecting small length changes in the spacecraft formation.

LISA WILL BE THE FIRST dedicated gravitational-wave observatory in space. This NASA/ESA mission, to be launched in 2013, will use three spacecraft to form a triangular laser interferometer spanning 3.1 million miles (5 million km) per side. They will orbit the Sun in fixed formation 20° behind Earth. Differences in the laser beams' travel times will signal passing gravity waves.

LEFT: TERRI FIELD; BELOW: NASA

/// BEYOND EINSTEIN: AN OVERVIEW

OBSERVATORIES, PROBES, AND VISIONS

Constellation-X and LISA form the backbone of NASA's Beyond Einstein program. Both probes are considered "great observatories," powerful space facilities like the Hubble Space Telescope and Chandra X-ray Observatory.

Constellation-X, which will extend current capabilities for high-resolution X-ray spectroscopy by up to 100 times, is designed to track spectral features of gas close to a black hole's event horizon and to trace the evolution of black holes by capturing detailed spectra from faint, distant quasars.

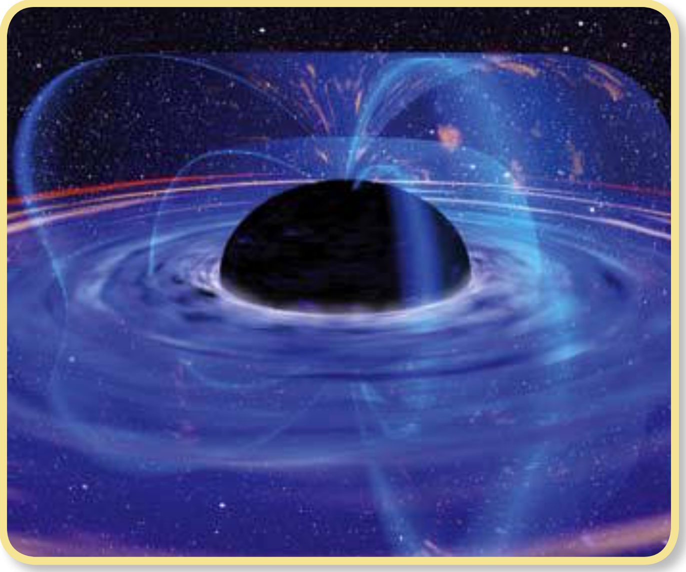
LISA will sense gravitational waves, opening up a new window on our violent universe. LISA will sense the ripples of space-time from merging black holes, produce the first complete survey of merging stars in the Milky Way, and set limits on events occurring in the universe's first fractions of a second.

A series of competitively selected "Einstein probes," each focused on a specific science question, forms the program's second segment and is designed to complement the great observatories. An **Inflation Probe** will examine how the cosmic microwave background is polarized, helping define the nature of the vacuum that drove inflation after the Big Bang.

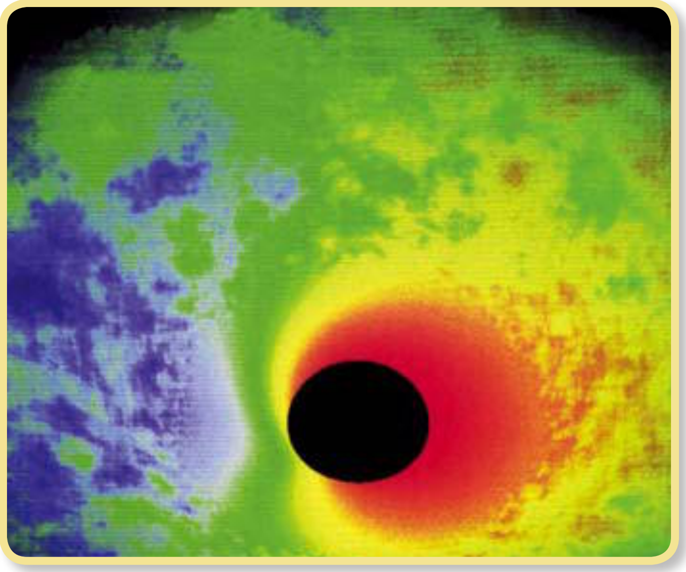
A **Black-Hole Finder** will perform a census of black holes, revealing their demographics and life cycles and identifying targets for study by Constellation-X. A **Dark Energy Probe** will measure the expansion of the universe at different epochs precisely; one proposal would use a wide-field space telescope to survey high-redshift supernovae.

The program's third element involves technology development and theoretical studies that will lead the way to two Einstein vision missions. A **Big Bang Observer** would expand on experience gained with both LISA and the Inflation Probe to detect higher-frequency gravitational waves emitted as the era of inflation began, providing a direct snapshot of space-time's creation.

And the second vision mission? Plans call for a **Black-Hole Imager** — an X-ray telescope with a million times the resolution of the Hubble Space Telescope that could directly study gas near a black hole's event horizon.
— *Francis Reddy*



AN ARTIST IMAGINES THE UNIMAGINABLE — the innermost region of a black hole in the center an active galaxy. An end point of NASA's Beyond Einstein program is a Black-Hole Imager capable of X-ray mapping at microarcsecond resolution. NASA



THIS SIMULATED IMAGE shows how the inner edge of a black hole's accretion disk might appear when directly detected. Rainbow colors reflect the change in X-ray wavelength caused by the disk's rapid rotation. NASA

What is dark energy?

Dark energy is the biggest mystery in physics and astronomy. It comprises about 70 percent of the universe, and we really don't have a clue what it is. Dark energy points to a fundamental problem with the standard model of physics and could provide the hints needed to unite general relativity with quantum mechanics.

Dark energy is the name given to the force accelerating the expansion of the universe, a landmark discovery in the late 1990s. How does Einstein fit in? Almost by accident.

Because Einstein originally thought the universe was static, he needed a counterbalance to keep gravity from causing the universe to implode. But when Edwin Hubble discovered the expansion of the universe, Einstein rejected his own idea, calling it his greatest blunder.

Einstein may have been wrong about being wrong. The expansion of the universe from the Big Bang appears to have slowed down as expected due to gravity — but that was several billion years ago. Something — this dark energy — then became the dominant force, and the universe has been accelerating ever since.

What could this force be? Richard Feynman and others who developed the quantum theory of matter realized "empty space" is full of temporary, or virtual, particles continually forming and destroying themselves. Physicists began to suspect that, indeed, these virtual particles ought to give the vacuum of space a repulsive form of energy, but they could not predict its magnitude. We still do not know how — or even if — the highly accelerated expansion in the early universe (called inflation) and the current accelerated expansion (due to dark energy) are related.

A space-based mission, called the Dark Energy Probe, will measure the expansion accurately enough to learn whether this energy is a constant property of empty space (as Einstein proposed) or whether it varies over time, as modern unification theories predict.

If … we see the slightest deviation between theory and observation, we will understand limitations in Einstein's equations.

At the black hole's edge

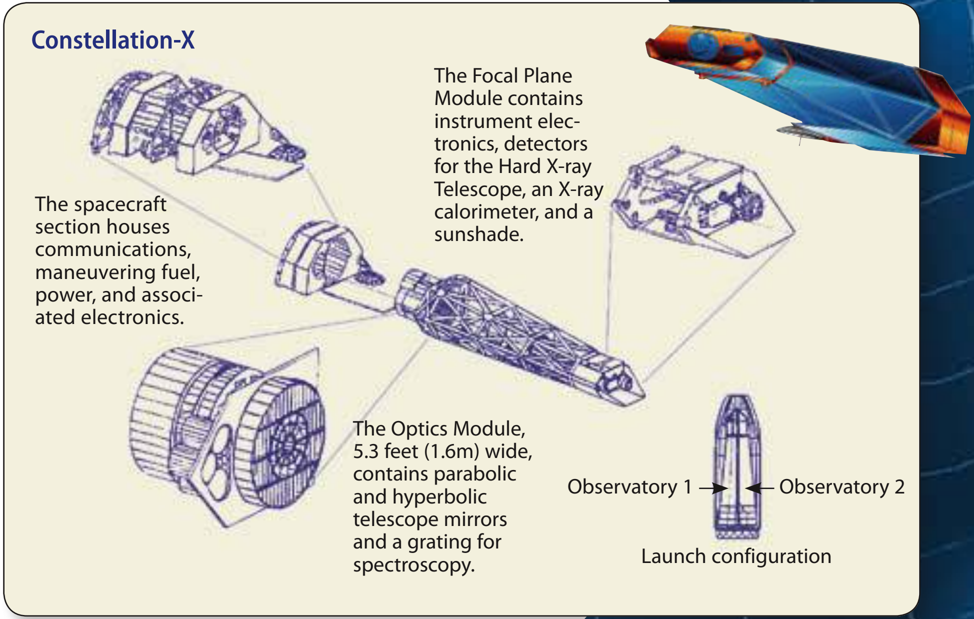
The greatest extremes of gravity are black holes that form in galactic centers and from the collapse of stars. We can study these invisible bodies by examining matter swirling into them, sometimes shooting off in jets, and by listening to the waves of distortion they make in space-time. New data from X-ray satellites, namely NASA's Chandra X-ray Observatory and the European Space Agency's (ESA) XMM-Newton, reveal regions in space where space-time appears to be dragged by a black hole, as Einstein's equations predict.

Yet what happens to matter as it moves closer to a black hole and crosses the event horizon, the theoretical border from which nothing can escape? Does time really come to a standstill? General relativity makes specific predictions about matter and energy close to a black hole. If, upon close scrutiny, we see the slightest deviation between theory and observation, we will understand limitations in Einstein's equations.

Two flagships of Beyond Einstein will take us closer than we've ever been to a black hole's event horizon and provide detailed pictures of what happens to space and time at the edges of these roiling vortices. LISA, a joint NASA-ESA mission now in formulation, will listen for gravitational waves created by merging black holes. Such waves, another prediction of general relativity, are analogous to light waves, moving at light speed and possessing a spectrum of frequencies. They have not yet been detected directly. Their detection would be a windfall discovery, offering an entirely new way to observe the universe.

Constellation-X is a multisatellite X-ray observatory. The satellites, flying in for-

CONSTELLATION-X will capture X rays by bending those grazing its curved, segmented mirror. Technicians use a mandrel (left) to form each mirror segment (below). NASA



The Focal Plane Module contains instrument electronics, detectors for the Hard X-ray Telescope, an X-ray calorimeter, and a sunshade.

The spacecraft section houses communications, maneuvering fuel, power, and associated electronics.

The Optics Module, 5.3 feet (1.6m) wide, contains parabolic and hyperbolic telescope mirrors and a grating for spectroscopy.

THE CONSTELLATION-X OBSERVATORIES will launch two at a time and station themselves at the quasi-stable L2 gravitational point some 930,000 miles (1.5 million km) from Earth opposite the Sun. The satellites will orbit close to one another, observing the same distant objects at the same time. By combining their data, all four planned observatories become 100 times more powerful than any previous single X-ray telescope. With a focused effort, say mission scientists, the first Constellation-X observatories could fly as soon as 2013, but NASA's current budget for the program puts off the first launch until at least 2016. TERRI FIELD; INSET: NASA

mation, will have the combined light-collecting power to make movies of warped space-time near a black hole. Constellation-X's strength will be spectroscopy, a method to analyze the physical properties of atoms near the black hole through the light they emit. Constellation-X will be 100 times more efficient than current observatories at collecting X rays.

As with LISA, Constellation-X will provide the tightest constraints yet on general relativity. Black holes are the ultimate gravity laboratories. Consider how Newton's law of gravity was used successfully to calculate planets' orbits around the Sun — except for Mercury's orbit. Careful measurements in the 19th century revealed the orientation of Mercury's orbit was off by about 40 arcseconds. What Newton's equation didn't account for was the Sun's gravity warping space-time near it; the other planets, farther from the Sun, aren't affected. Einstein's equations pegged Mercury's unusual orbit. As the relatively weak gravity from the Sun revealed a flaw in Newton's math, so too might careful study of black holes reveal flaws in Einstein's math.

Both LISA, which will measure black-hole distances, and Constellation-X, which will study galaxy-cluster dynamics, will provide insight into the dark-energy mystery.

The Beyond Einstein Black-Hole Finder will conduct a true census. This probe will complement Constellation-X and LISA, find black-hole sources these observatories can study, determine different black hole classes, and reveal the role these objects play in shaping galaxies.

These efforts will culminate in a direct image of a black hole's event horizon, which would be a breathtaking achievement. The Black-Hole Imager would be an X-ray telescope with resolution a million times sharper than Hubble's. This might entail multiple mirrors and detectors flying in formation, similar to radio interferometers currently stretched across the United States. Dedicated technological development could make this goal a reality within two decades. That snapshot would provide the undeniable proof of black holes' existence.

What powered the Big Bang?

Scientists in the 1920s realized soon enough that the equations of general

EINSTEIN'S LEGACY includes cosmic acceleration — an idea he discarded — and "lensing" of light by massive objects, such as Abell 1689, a galaxy cluster 2.2 billion light-years away. Arc-shape objects in this view are distorted images of background galaxies. NASA/ESA/STScI

relativity imply the universe is expanding. The universe was smaller yesterday, smaller yet the day before, and so on; and at some point, there must have been a moment when space and time as we know them came into existence — the Big Bang. Yet what sparked the Big Bang?

Wouldn't it be nice to look back in time to the moment of the cosmos' creation to see what happened? That's our plan. Gravitational waves hardly interact with matter (which is why they're so hard to detect) and effortlessly penetrate the fog of the early universe.

We can infer what happened a fraction of a second after the universe began by studying the cosmic microwave background — the Big Bang's afterglow. This isn't early enough to see that moment when gravity might have been united with the other fundamental forces, but we are getting closer.

During the last decade, sky maps of this residual microwave radiation — first by NASA's Cosmic Background Explorer (COBE) satellite and more recently by other experiments, including the NSF-funded Antarctic balloon flights and NASA's Wilkinson Microwave Anisotropy Probe (WMAP) — have displayed the wrinkles imprinted on the universe in its first moments. These maps reveal slight temperature variations in the sky (a little warmer here, a little colder there) that point back to density differences (a little more matter here, a little less matter there) within a second of the Big Bang. Regions with higher density attracted more matter, forming galaxies over the course of hundreds of millions of years.

Understanding what caused that initial lumpiness will point us to what powered the Big Bang. We need to probe a little deeper, though. Modern theoretical ideas predict the wrinkles COBE discovered arose from two kinds of primordial particles: from the energy field that powered the Big Bang, and gravitons, fundamental particles of space and time.

One theory related to this is called inflation, which states that 100 billionths of a trillionth of a trillionth of a second after the Big Bang, the visible universe grew from the size of an atom to a grapefruit in less than a thousandth of a second. Inflation occurred just after gravity divorced itself from the other fundamental forces. The universe was cooling and undergoing a phase transition then, sort of like water condensing from steam.

One possible implementation of the Beyond Einstein Inflation Probe will be to study how radiation in the cosmic microwave background is polarized, just as WMAP measured temperatures. The polarization pattern was set in place by gravitational waves generated in the Big Bang, and its details will reveal if and how inflation stretched and smoothed the universe.

Our analyses of cosmic polarization will reveal the effect of gravitons, or gravity "particles." This, in turn, will help distinguish between competing theories of what sparked inflation and the Big Bang.

This is a step-by-step process. An NSF-funded South Pole observatory called DASI found the first evidence for polarization in 2002. An ESA mission called Planck, planned for a 2007 launch, will make more sensitive measurements, as will balloon-borne instruments. The Inflation Probe will build upon this work, ultimately allowing us to piece together the story of how time, space, and energy worked together to power the Big Bang.

Beyond Einstein's Big Bang Observer would be a gravitational-wave detector tuned to the ultra-low frequency of the wave created by the Big Bang, with a wavelength spanning 3 billion light-years. As with the Black-Hole Imager, Big Bang Observer would be a crowning achievement. This would place us at the moment of the Big Bang, providing the first direct measurement of gravitons and a view of the creation of space-time. This mission could fly within 30 years.

Fulfilling Einstein's dream

Einstein sought, but never achieved, an understanding of how nature works at its deepest level. He struggled his entire life to fold electromagnetism — a quantum force — into general relativity and to find a unified theory. We now seek to fulfill Einstein's quest through a program of missions we are designing today to carry out over the next decade.

There is tangible excitement among scientists. We are on the verge of the next scientific breakthrough that will define the 21st century and beyond.

This is the new scientific revolution, a race for the next great leap forward. Scientists around the world from a variety of once-disparate disciplines are uniting for the cause

The answers we seek require new theories. Like Einstein's ideas, modern theories make fantastic predictions that seem hard to believe: unseen dimensions and entire universes beyond our own.

We must find facts to confront and guide these new theories. Thus, we will follow matter to the very brink of black holes and detect space-time as it formed at the beginning of the universe, and we will use breakthrough technologies to see beyond the vision of Einstein — to the extremities of existence. ■

ONLINE EXTRA Before LISA, there's LISA Pathfinder. Learn more about this mission at www.astronomy.com/to

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Jesus Preaching to the Multitudes by Gustave Doré from *The Doré Bible Illustrations.*

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Professor Ehrman is a razor-sharp lecturer and a consummate scholar with a full and ready command of his material. He is Professor of Religious Studies at The University of North Carolina at Chapel Hill, where he has taught since 1988. He has received the Students' Undergraduate Teaching Award, the Hettleman Prize for Artistic and Scholarly Achievement, and the Bowman and Gordon Gray Award for Excellence in Teaching.

His textbook on the New Testament is the most widely used in universities today. In addition to his textbook, Professor Ehrman has written dozens of book reviews and scholarly articles, and has written or edited 12 books. He was recently featured in *Time* magazine for his book *Lost Christianities.*

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Offer Good Through: November 5, 2005

BY MARTIN RATCLIFFE AND ALISTER LING

OCTOBER 05

Lunar and solar eclipses grace different hemispheres of Earth, but October's highlight should be Mars looming at its biggest for the year.

Eclipses span the globe

Thousands of observers across Europe will converge on Spain and Portugal for a spectacular annular solar eclipse the morning of October 3. Annular refers to a ring of sunlight (the Latin word *anulus* means ring), rather than a once-a-year event. Although the Moon crosses the center of the Sun's face, it is slightly too small to cover it all, and an awesome ring of fire remains. After the narrow path of annularity leaves Europe, it crosses northern and eastern Africa. Residents in the rest of Europe and most of Africa will see a partial eclipse.

LAWRENCE GRUSS

A RING OF SUNLIGHT will dazzle those in Spain, Portugal, and a strip of Africa October 3, mimicking this view from May 10, 1994.

Viewing a non-total solar eclipse poses danger to your eyesight. Use a good solar filter if you watch this event directly. You can pick up inexpensive but high-quality solar-eclipse "glasses" at most planetaria.

On the morning of October 17, a black shadow moves slowly across the Moon's face. The d rwies takes a small but noticeable bite out of the Full Moon starting at 7:34 A.M. EDT (4:34 A.M. PDT). Our only natural satellite passes just inside Earth's shadow, in what astronomers call a partial lunar eclipse.

The best views of this eclipse come from lands rimming the Pacific Ocean and on Pacific islands. People in the western half of North America will see the entire eclipse, which wraps up at 5:32 A.M. PDT. Farther east, the Moon sets before the eclipse ends. Yet even from the East Coast, careful observers will see the Moon's southern half dim a bit just before it sets.

Have you noticed what looks like a plane's landing light in the southwest about 45 minutes after sunset? This beacon is actually our sister planet, Venus, whose cloud-choked atmosphere reflects most of the sunlight hitting it. Point a small telescope toward the planet, and you'll see something that looks like a miniature, bloated half-Moon. On the evening of October 6, use binoculars to find a thin crescent Moon sharing the field of view to the lower right.

A second beacon rises in the east during mid-evening hours. Mars appears orange, despite its "Red Planet" nickname. Experienced observers consider the disk Mars now presents through a telescope to be huge, but newcomers need patience and practice to eke out subtle details across the object's small face. Avoid observing Mars when it lies low in the sky, because the image degrades as the light traverses Earth's turbulent atmosphere. The image steadies as Mars climbs higher, around midnight.

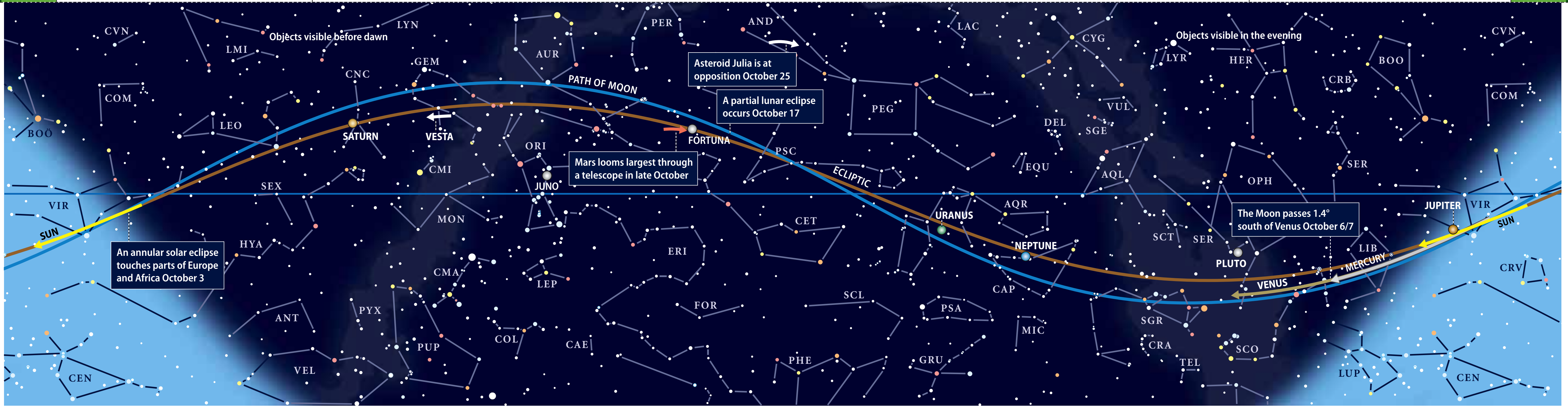
The quick, fiery trails popularly known as "shooting stars," and officially as meteors, result when tiny dust motes burn up in Earth's upper atmosphere. When our planet crosses a dust stream ejected by a comet, we see a meteor shower. On the morning of October 21, dust from Comet Halley should produce 5 to 15 flashes per hour. The meteors emanate from the celestial hunter, Orion, so astronomers call them the Orionids. A waning gibbous Moon will drown out fainter meteors, so the show won't be as good as in some years.

Earlier in the month, Earth may sweep through a dense dust trail left behind by Comet 21P/Giacobini-Zinner. Astronomers calculate we'll barely miss it; but just in case, keep an eye on the sky the morning and evening of October 8. A dark sky will help you see any outburst from the Draconid meteor shower.

Early morning risers will see Saturn gleaming high in the south. Through a telescope, the rings appear noticeably less open than they did a year ago.

Planets this month

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.


Objects visible before dawn
Objects visible in the evening
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BOO
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PATH OF MOON
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TEL
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LUP
CEN
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PYX
PUP
COL
CAE
PHE
GRU
VEL

Asteroid Julia is at opposition October 25

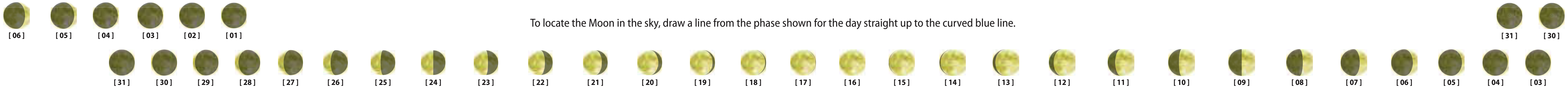
A partial lunar eclipse occurs October 17

Mars looms largest through a telescope in late October

The Moon passes 1.4° south of Venus October 6/7

An annular solar eclipse touches parts of Europe and Africa October 3

To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.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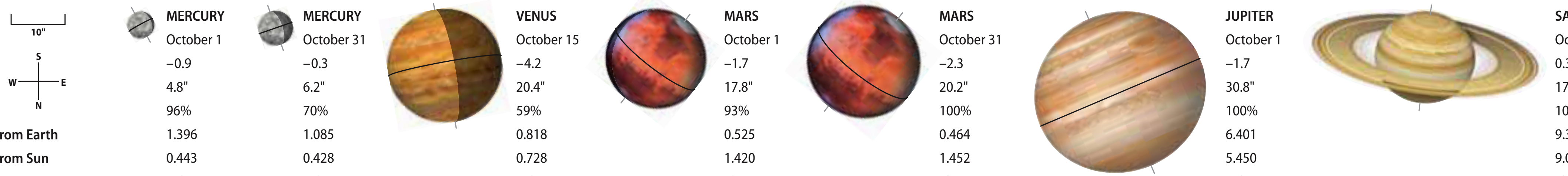
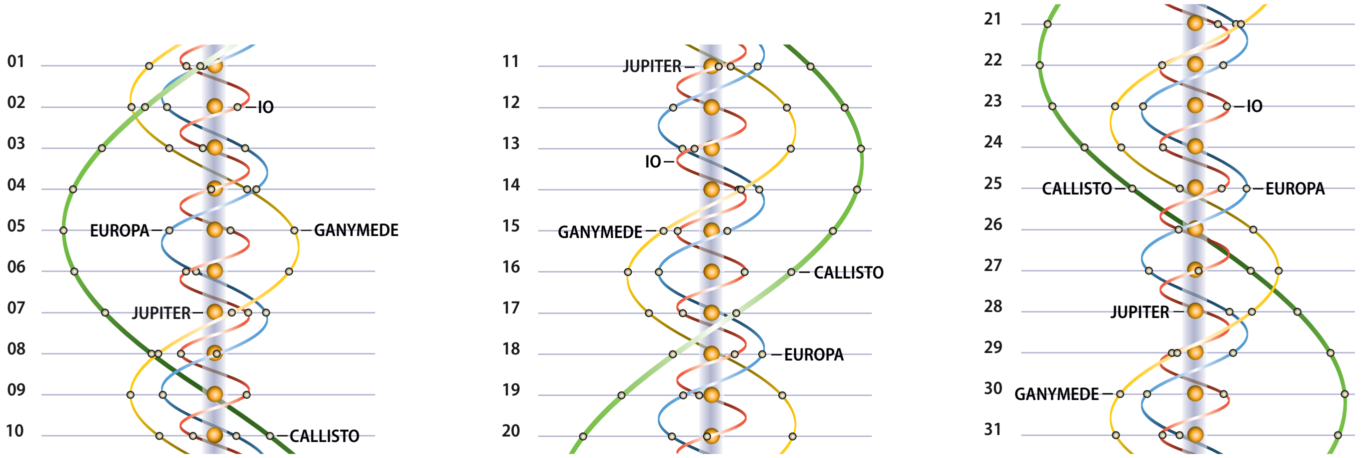


PLANETS	MERCURY	MERCURY	VENUS	MARS	MARS	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	October 1	October 31	October 15	October 1	October 31	October 1	October 15	October 15	October 15	October 15
Magnitude	–0.9	–0.3	–4.2	–1.7	–2.3	–1.7	0.3	5.8	7.9	13.9
Angular size	4.8"	6.2"	20.4"	17.8"	20.2"	30.8"	17.8"	3.6"	2.3"	0.1"
Illumination	96%	70%	59%	93%	100%	100%	100%	100%	100%	100%
Distance (AU) from Earth	1.396	1.085	0.818	0.525	0.464	6.401	9.357	19.348	29.654	31.491
Distance (AU) from Sun	0.443	0.428	0.728	1.420	1.452	5.450	9.095	20.072	30.060	31.018
Right ascension (2000.0)	13h05.6m	15h51.5m	16h21.1m	3h25.9m	3h01.3m	13h32.3m	8h49.9m	22h36.7m	21h09.1m	17h28.0m
Declination (2000.0)	–6°39'	–22°56'	–24°24'	16°26'	16°13'	–8°30'	18°11'	–9°37'	–16°33'	–15°31'

ALL ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

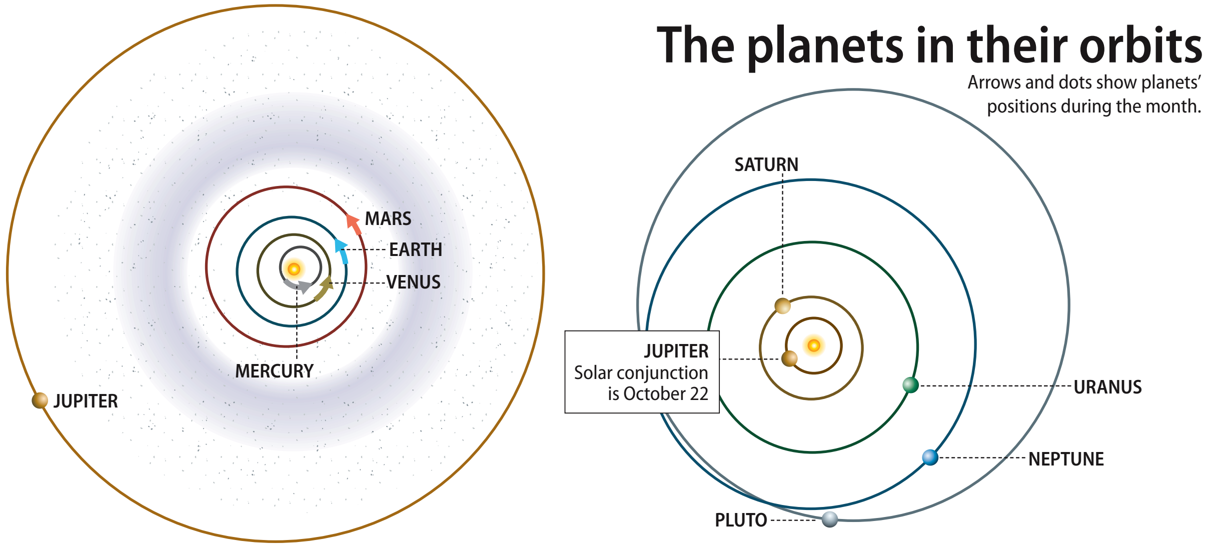
Jupiter's moons

Dots display positions of Galilean satellites at 10 P.M. EDT on date shown. South is at top to match the view through a telescope.



The planets in their orbits

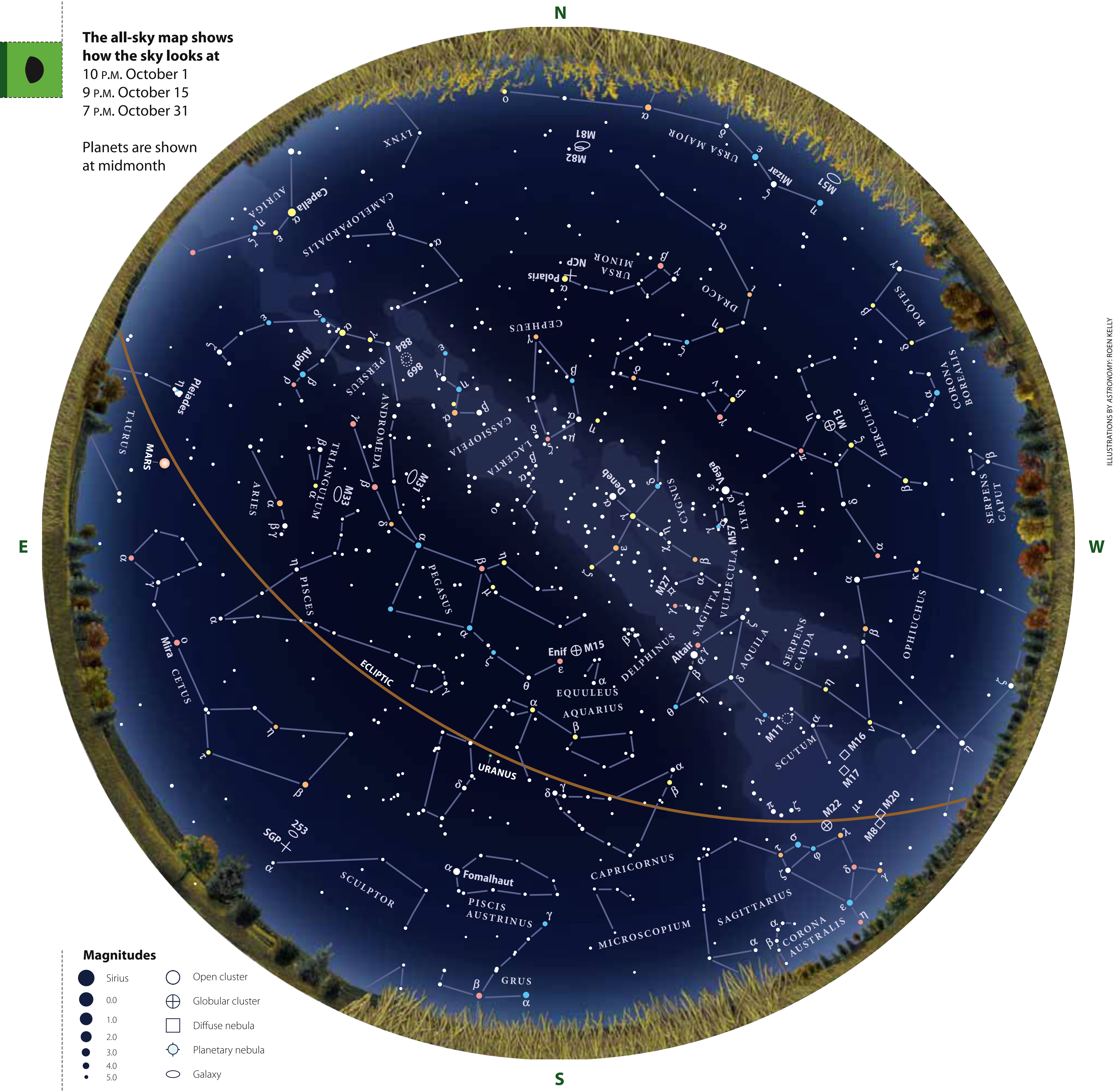
Arrows and dots show planets' positions during the month.


MARS
EARTH
VENUS
MERCURY
JUPITER
SATURN
URANUS
NEPTUNE
PLUTO

JUPITER
Solar conjunction is October 22

The all-sky map shows how the sky looks at
10 P.M. October 1
9 P.M. October 15
7 P.M. October 31

Planets are shown at midmonth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NCP
Polaris
DRACO
BOÖTES
CEPHEUS
PERSEUS
884
869
Algol
Pleiades
TAURUS
MARS
CASSIOPEIA
ANDROMEDA
TRIANGULUM
M33
M31
ARIES
LACERTA
Deneb
CYGNUS
Vega
LYRA
M57
HERCULES
M13
CORONA BOREALIS
SERPENS CAPUT
OPHIUCHUS
PISCES
PEGASUS
M27
VULPECULA
SAGITTA
Altair
AQUILA
SERPENS CAUDA
Mira
CETUS
ECLIPTIC
Enif
M15
EQUULEUS
DELPHINUS
AQUARIUS
M11
SCUTUM
M16
M17
URANUS
M22
M20
M8
SGP
253
SCULPTOR
Fomalhaut
PISCIS AUSTRINUS
CAPRICORNUS
SAGITTARIUS
MICROSCOPIUM
CORONA AUSTRALIS
GRUS

Magnitudes

●	Sirius	○	Open cluster
●	0.0	⊕	Globular cluster
●	1.0	☐	Diffuse nebula
●	2.0	⌖	Planetary nebula
●	3.0	⬭	Galaxy
●	4.0		
•	5.0		

This map portrays the sky as seen near 35° north latitude at times shown in the upper left corner of the page. Located just outside the map are the four directions: north, south, east, and west. To find stars above your horizon, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

october 05

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
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ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

01 Mars is stationary, 6 A.M. EDT

03 New Moon is at 6:28 A.M. EDT; annular solar eclipse

07 The Moon passes 1.4° south of Venus, 2 A.M. EDT

The Moon passes 0.2° north of Antares, 9 P.M. EDT

08 Draconid meteor shower peaks

10 First Quarter Moon is at 3:01 P.M. EDT

12 The Moon passes 5° south of Neptune, 11 A.M. EDT

14 The Moon passes 3° south of Uranus, 1 A.M. EDT

The Moon is at perigee (227,080 miles from Earth), 9:58 A.M. EDT

16 Venus passes 1.6° north of Antares, 2 P.M. EDT

17 Full Moon is at 8:14 A.M. EDT; partial lunar eclipse

19 The Moon passes 5° north of Mars, 9 A.M. EDT

21 Orionid meteor shower peaks

22 Jupiter is in conjunction with the Sun, 9 A.M. EDT

24 Last Quarter Moon is at 9:17 P.M. EDT

25 The Moon passes 4° north of Saturn, 1 P.M. EDT

26 The Moon is at apogee (251,341 miles from Earth), 5:33 A.M. EDT

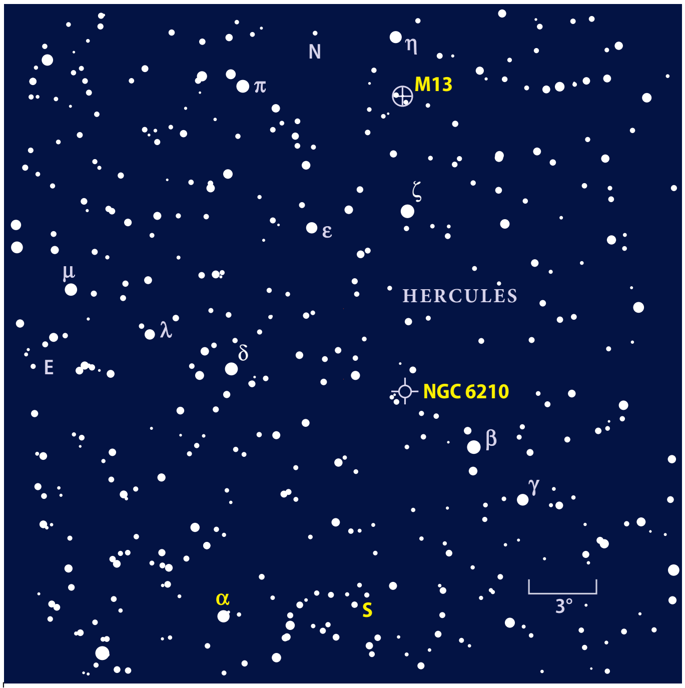
29 Mars is closest to Earth (43.1 million miles away), 11 P.M. EDT

31 The Moon passes 1.2° north of Spica, 2 P.M. EST

ONLINE EXTRA For definitions of terms, visit www.astronomy.com/glossary

THE DEEP SKY

Best known for its gorgeous globular star cluster, M13, Hercules harbors more colorful treasures, including an aquamarine cocoon and a glowing carbon ember.



ASTRONOMY: THEO COBB

THE STRONGMAN HERCULES boasts M13, the northern sky's brightest globular, but don't overlook the stunning planetary NGC 6210 and several intriguing stars there.

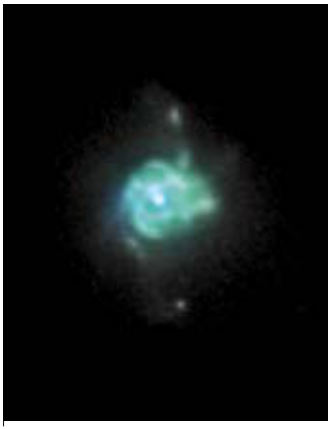
A starry sight

Who can resist seeing countless stars packed into a tight ball? A telescopic view of the grand globular cluster Messier 13 always draws satisfied sighs, even from experienced observers. It's a great way to start an observing session. But instead of hopping along the road to the next object in the Messier catalog, let's veer off the beaten path and put some color into your telescope.

At the southern end of Hercules lies the double star Alpha (α) Herculis, to the naked eye an unremarkable star that belies its true nature. Observers report the companion has an emerald or blue-green hue. Alpha is a tight double, and small telescopes need to operate close to their power limit of 150–200x to split the pair. The 5" gap is a bit wider than summer's famous Double Double, but only one-quarter the apparent size of Saturn's disk.

Don't let the fact that stars can't be green stop you from enjoying this unusual sight. The human visual system often skews the color of an object by injecting the complementary hue onto the companion. You can play with this illusion in daylight: Find an orange-red object and stare at it for 15 or 20 seconds, then shift your gaze to a white wall to see the reversed color scheme.

No green stars exist in nature because a star whose energy peaks in the green part of the spectrum also produces copious amounts of blue and red light. Putting them all together produces the ubiquitous white star.



RICH AND ANNE QUIGLEY/ADAM BLOCK/NOAO/AURA/NSF

THE BLUE-GREEN GLOW of NGC 6210 stands out through 6-inch and larger scopes. This 9th-magnitude planetary nebula measures 21" across.

Greenish glow

A real aquamarine gem does exist, however. The bright planetary nebula NGC 6210 lies a third of the way and a bit north of a line from Beta (β) to Delta (δ) Herculis. At 9th magnitude and a relatively compact 21" size, the bright glow is easy to pick out through a 6-inch scope from a suburban backyard.

A planetary nebula is a gas shell representing the outer layers of a dying star. The star's white-hot core causes atoms of hydrogen, nitrogen, and oxygen to fluoresce at specific colors. One set of those bright spectral lines clusters in the green, near where the human eye detects color best.

When viewing NGC 6210, don't use averted vision. Useful for observing faint objects, this method of glancing to the side lets light fall on the most light-sensitive part of your eye. But here, instead, look straight at NGC 6210 so its light hits your eyes' color receptors.

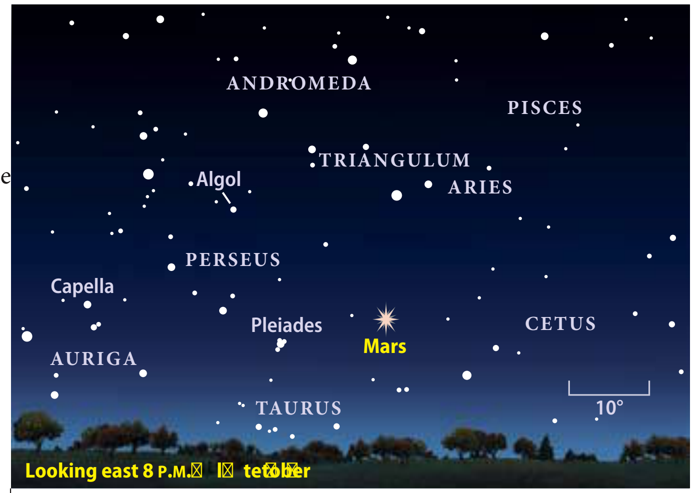
In stark contrast to green stars, orange ones are common. Cooler suns radiate most of their light toward the red end of the spectrum. The deficiency of blue light results in an orange hue. This month, the long-period variable star S Herculis should peak around magnitude 7.6, although no one knows precisely how bright it will get. As it fades slowly in the following weeks, its rusty color will shift toward a deeper orange.

If you're seeking a greater challenge in this area of sky, stop by NGC 6181. This 12th-magnitude spiral galaxy spans just 2.3' by 0.9'. Wait for the dark of the Moon in early or late October before attempting to view this dim object from the countryside.

Martin Ratcliffe is former president of the International Planetarium Society. Alister Ling is a meteorologist for Environment Canada.

THE PLANETS

The Red Planet peaks in late October and early November. This spectacular object rises in the east just as the brilliant evening star, Venus, sets in the west.



ASTRONOMY: THEO COBB

THE RED PLANET RISES as darkness falls in October, dominating the eastern sky all evening. The best telescopic views, however, won't come until after midnight.

Mars certainly will grab the lion's share of attention this month, but five other planets will be on display before Mars rises in mid-evening. The first of these, and the toughest one to spot, is **Mercury**. Its current evening apparition is unfavorable for Northern Hemisphere observers. The reason: Mercury lies south of the ecliptic — the apparent path of the Sun across the sky that the planets closely follow — and the ecliptic makes a shallow angle to the western horizon during evening twilight. This causes the innermost planet to hug the western horizon even as its elongation from the Sun increases.

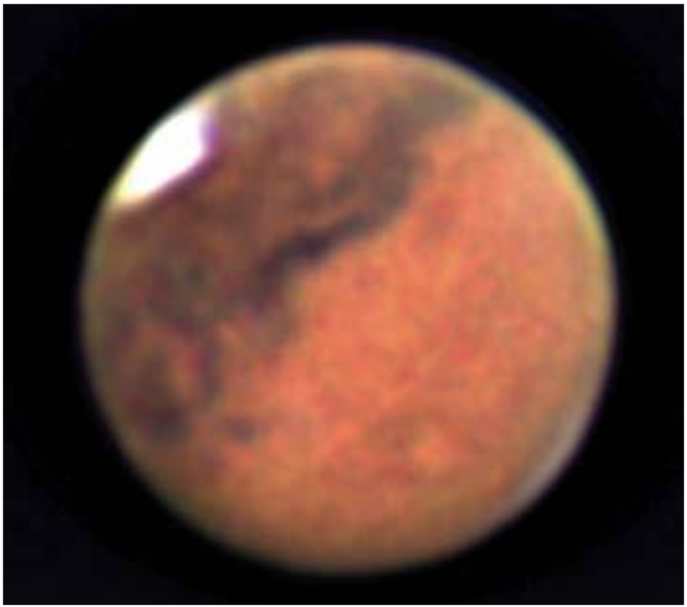
Although it remains visible only in bright twilight, Mercury will be easier to find around October 5, when it passes 1.5° south of **Jupiter**. Jupiter shines so brightly then that observers can catch it with binoculars even when it hangs low in the twilight. It gleams at magnitude –1.7, while Mercury shines at magnitude –0.7. A slender crescent Moon lies farther south along the horizon, and the brilliant evening star, **Venus**, appears unmistakable in the southwest.

The following evening, October 6, the Moon lies 4° west of Venus. The attractive pairing shows up best through binoculars. Use a telescope if you want to see Venus' disk. That evening, it appears 19" across and 62-percent lit. By the end of the month, Venus has grown to 24" in diameter and its phase dwindles to half-lit. Venus slides 1.6° north of 1st-magnitude Antares October 16. You should be able to see their contrasting colors — the planet appears slightly off-white, while the red supergiant star shows a ruddy hue.

Neptune remains among the background stars of Capricornus the Sea Goat. Glowing at magnitude 7.9, it's fairly easy to pick out with binoculars. It lies 1° (2 Moon-widths) northeast of the 4th-magnitude star Theta (θ) Capricorni and just 0.1° northeast of a 7th-magnitude star. You can use the latter as a guide to the slightly fainter planet. Neptune completes its retrograde, or westward, loop and comes to a standstill near this star October 26. If you watch nightly, you'll be able to track Neptune's slow motion relative to the star. Through a telescope, Neptune displays a 2.3"-diameter disk with a subtle blue-gray color.

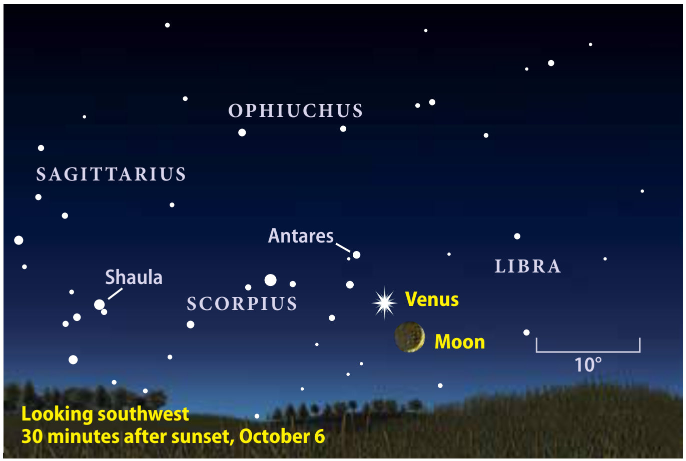
Neptune's brighter cousin, **Uranus**, is an easy binocular target and can be glimpsed even with the naked eye under a dark sky. To find it, first locate the 4th-magnitude star Lambda (λ) Aquarii and then slide 6° southwest to 5th-magnitude Sigma (σ) Aqr. Uranus, which glows at magnitude 5.8, is the brightest object between these two stars. The planet creeps closer to Sigma throughout October, ending the month just 1.6° to the northeast. A telescope clearly shows the planet's 3.6"-diameter disk and distinct blue-green color.

The most spectacular planet this month has to be **Mars**. October brings the Red Planet



JOE PETRICK

MARS' GLEAMING WHITE south polar cap and subtle dark surface markings will stand out as the Red Planet looms large this month.



ASTRONOMY: THEO COBB

A SLENDER CRESCENT MOON passes gleaming Venus October 6, when the two dominate the evening twilight.

closer to Earth than at any time since its historic apparition in summer 2003. On October 1, Mars lies 49 million miles from Earth. The gap closes to 43 million miles by the 29th.

The proximity makes Mars appear as large as possible through a telescope. At the beginning of October, the planet measures 17.8" across, a figure that grows to 20.2" on the 29th. It remains 20.0" across or bigger in the 2 weeks from October 23 to November 6.

Mars also brightens considerably during October. On the 1st, it shines brilliantly at magnitude –1.7. Yet it appears 70-percent brighter by the 31st, reaching magnitude –2.3. It continues to brighten a bit during the first week of November, peaking when it lies opposite the Sun in our sky November 7.

Mars reaches opposition a week after its closest point to Earth because it has a noticeably elliptical orbit. If Earth and Mars had circular orbits, opposition and closest approach would coincide.

The current apparition won't be as spectacular as the 2003 perihelic opposition. Even at its best this year, Mars will appear 20-percent smaller than it did 2 years ago. However, for Northern Hemisphere observers, the planet stands 30° higher in the sky than in 2003. With the light from Mars traveling a much shorter path through Earth's turbulent atmosphere, views of Mars through a telescope should be crisper than in 2003.

Mars moves from Taurus the Bull into Aries the Ram this month. It rises just after 8:30 P.M. local daylight time October 1 and pokes above the horizon during twilight by month's end. For telescope owners, the best time to view Mars during October is when it lies highest in the sky — between approximately midnight and 4 A.M. local daylight time.

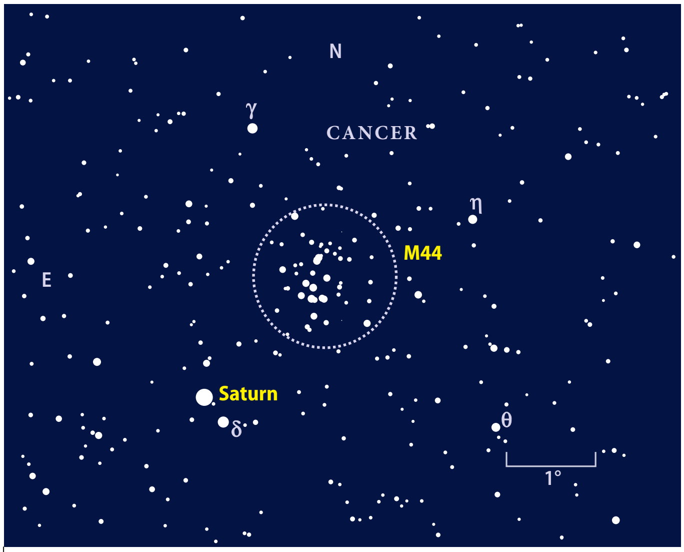
The most striking feature on Mars' surface will be the south polar cap. The brilliant white cap stands in stark contrast to the rest of the ochre disk and gains prominence because the planet's south pole currently tilts in our direction. With summer now in full swing in the martian southern hemisphere, you should notice the icy cap shrinking.

Tracking the more subtle dark surface markings takes considerably more experience. Observe Mars as often as you can — the practice will have you picking out detail you never would have thought possible during your first looks.

Each week, different features will be on view. One martian day, or sol, lasts about 40 minutes longer than an Earth day. Consequently, if you observe Mars at the same time each night, surface features appear to rotate backward slowly. The similarity in the two planets' rotation periods means the same martian features remain well-positioned for viewing about a week at a time.

In the prime after-midnight hours of early October, features around Mare Cimmerium will be on view for North American observers. By the second week of October, the open deserts of Amazonis and Mare Sirenum will face observers. In the third week, Solis Lacus and Mare Erythraeum are in prime position after midnight. This longitude region offers some of the best viewing, with many variations of light and dark features on both large and small scales. Syrtis Major, one of the planet's darkest and most recognizable features, moves into a central location on the disk at the end of October.

While Mars rides high in the south, **Saturn** climbs higher in the east. The ringed planet rises after midnight among the background stars of Cancer the Crab, just a few degrees from the Beehive star cluster (M44). It shines at magnitude 0.3, far brighter than the dim stars of Cancer. A telescope shows the planet's 18"-diameter disk and the magnificent rings, which span 40" this month. On October 25, Saturn lies 6° below the Last Quarter Moon.



ASTRONOMY: THEO COBB

SATURN JOINS THE BEEHIVE CLUSTER (M44) throughout October. Although Saturn shines brightly, you'll need binoculars to get a good view of M44.

METEORS AND MOONS

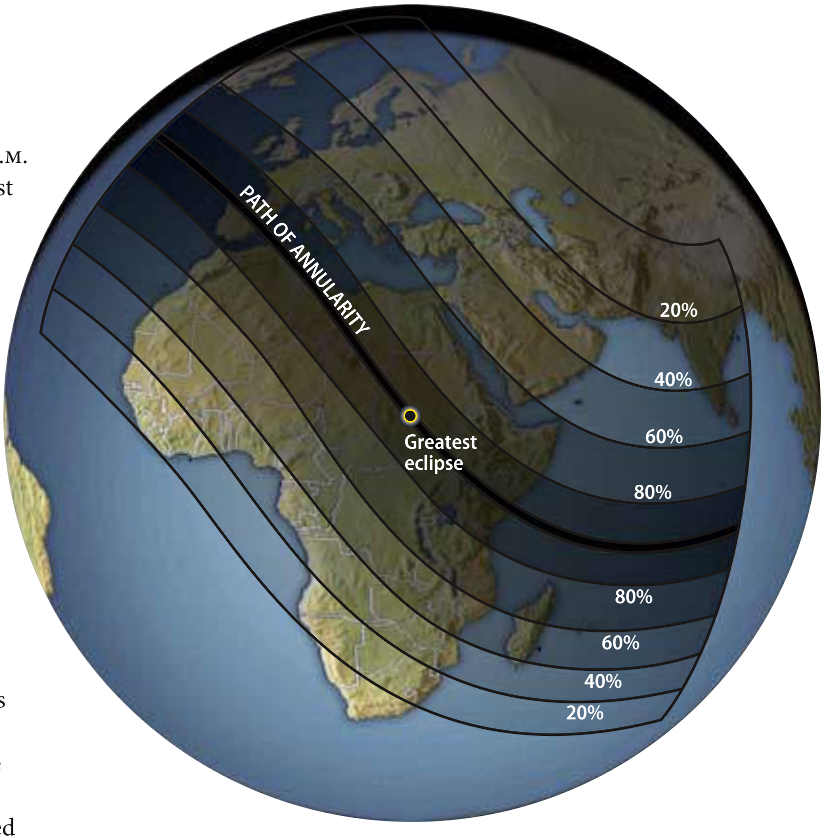
The M on and E☒ rth danc with each other's shadow this month, rewarding observers with both a lunar☒ an solar eclipse. These events may trump a possible Draconid meteor outbudst.

A pair of eclipses

Opposite sides of the globe are favored for the October 3 solar eclipse and the October 17 lunar eclipse. On the 3rd, the Moon passes directly between the Sun and Earth. Because the Moon then lies fairly far from Earth, it can't cover all of the Sun. Instead, observers along the central line will see a ring of sunlight — an annular eclipse.

The 100-mile-wide path of annularity stretches from Portugal and Spain across the Mediterranean Sea, and then dives through Africa from Algeria to Somalia. All of Europe, most of Africa, and much of southern and western Asia will see a partial eclipse. As always, when viewing the Sun, use a proper solar filter.

Two weeks after this eclipse, the Moon passes into Earth's shadow October 17. Unfortunately, it's not a direct hit — at peak, only 7 percent of the Moon will be hidden. (Maximum eclipse occurs at 8:03 A.M. EDT, 5:03 A.M. PDT.) The best views come from the Pacific Ocean and land surrounding it. The western half of North America will see the eclipse before dawn; the eastern half will see the start of the eclipse before moonset.



MUCH OF THE OLD WORLD will see a partial solar Vclipse October 3, while viewers along a narrow path in Europe and Africa will revel at an annular eclipse. *ASTRO OMY*:ROEN KELLY

A shower or two

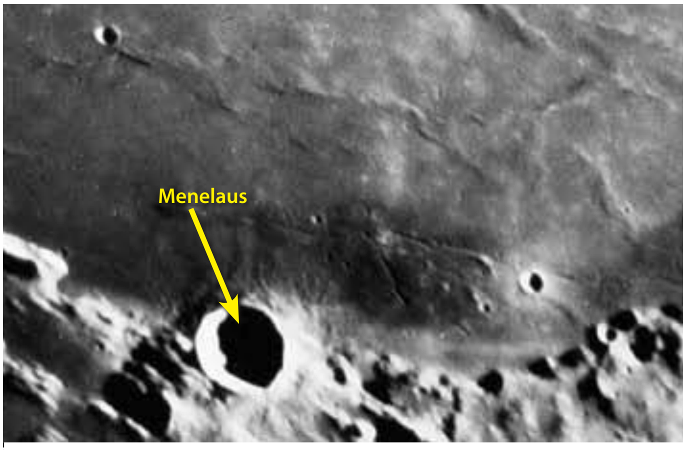
October's premier meteor shower is usually the Orionids, which typically produces 10 to 20 meteors per hour. Unfortunately, the shower's peak this year comes October 21, coinciding with a waning gibbous Moon. The Moon will drown out faint Orionids, cutting the observed number significantly.

All may not be lost this month, however. The typically minor Draconid shower could produce an outburst. The meteor shower's parent comet, 21P/Giacobini-Zinner, reached perihelion this summer. Similar geometries in the past have produced outbursts with hundreds of meteors per hour.

Astronomers don't know if the Draconids will put on a show this year, so the only way to find out is to look. The radiant lies in the head of Draco the Dragon, a circumpolar constellation from much of the Northern Hemisphere. The peak should come October 8, with the best conditions just before dawn that morning or in the early evening hours.

Shores of Serenity

On the southern rim of Mare Serenitatis lies the bright crater Menelaus. The crater spans 17 miles and has a clearly defined rim and terraced walls. It appears brilliant around Full Moon, when asymmetric rays emanate from the crater. Under low Sun angles, several lava flows can be seen across Mare Serenitatis, indicating numerous episodes of flooding. The lava runs right up to the mountain walls adjacent to Menelaus. The Sun rises over the crater October 9, a week after New Moon.



FROM CONSOLIDATED LUNAR ATLAS (LPL/UA)

LUNAR CRARER MENELAUS sits on the southern shore of Mare Serenitatis. The crater looks best a week after New Moon.

COMETS AND ASTEROIDS

Two challenging comets will capture observers' attention as each passes near a bright star cluster.

A new comet brightens

When Australian astronomer Robert McNaught discovered a 17th-magnitude fuzzball March 12, 2005, he didn't know it would turn into anything special. But Comet C/2005 E2 (McNaught) is setting us up for several months of good comet-observing. It reaches its closest point to the Sun next February, when it lies just inside Mars' orbit. As Earth slowly catches up to it, its brightness will climb from 11th magnitude this month to perhaps 9th magnitude early next spring.

To get a good look at Comet McNaught, observe from a dark-sky site when the Moon is out of the evening sky. Try in either the first or last week of October. Bright moonlight will not hamper digital imagers, however, who have the chance to capture a rare event October 16. The comet then grazes the globular cluster M55 in Sagittarius, likely obscuring stellar pinpoints on the fringe of the great cluster. (M55's brightest stars glow at magnitude 11.2.)

Deep-sky observers with big scopes, 16 inches or more in aperture, should try viewing this conjunction visually. At any other time, M55 looks impressive through a 10-inch scope because thousands of its stars resolve into a countless mass of granulating specks.

During the next few months, Comet McNaught will never stray far from the ecliptic. It passes close to Neptune in mid-December and eventually will join some galaxies in Aries at the end of March before disappearing into the Sun's glare.

An old comet fades

Comet 9P/Tempel 1 floats near M6, the beautiful Butterfly star cluster, the evening of October 1. Tempel 1 probably will have faded to 13th magnitude by then, so you'll need a 12- to 16-inch scope to see the event.

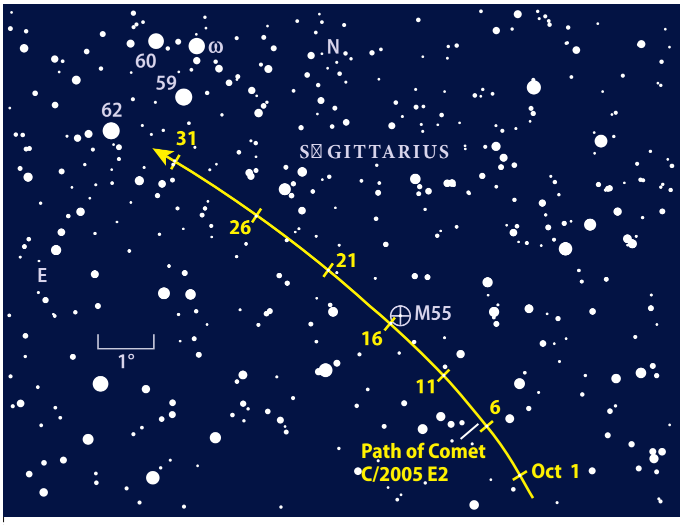
This is the comet smacked by NASA's Deep Impact mission in early July (see "Blasting the past" on page 72). At the time, astronomers hoped the collision would expose lots of fresh ice to the Sun's glare, which would boost the comet's brightness significantly. However, this optimistic scenario doesn't seem to have played out. Instead, a bright dust plume erupted from Tempel 1, creating a brightness spike that lasted about a week.

Still, comets are unpredictable beasts, and no one knows what Tempel 1 will be doing in October. The comet could be a couple of magnitudes brighter than predicted, and therefore much easier to view.

Rock Scorpion

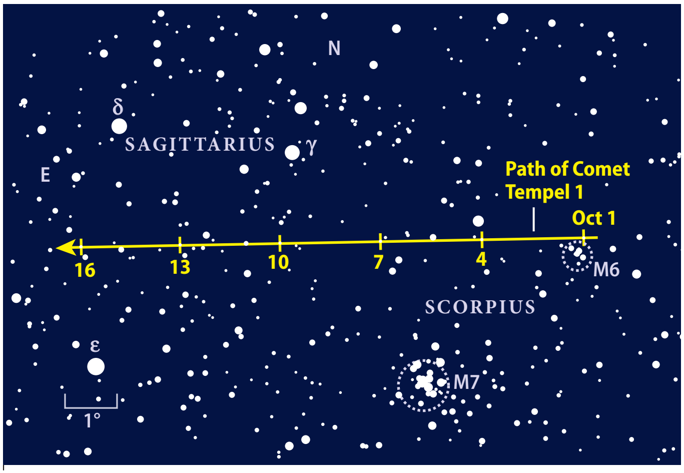
One of the brightest asteroids lies low in the southwest as darkness falls. Ceres glows at 9th magnitude among the stars of Scorpius. Because this area includes the outskirts of the Milky Way's central bulge, Ceres will be tough to identify against the multitude of background stars. On October 4, watch it close in on Omega^1 (ω^1) and Omega^2 (ω^2) Scorpii.

While you're in this area, take a close look at the impressive double stars Nu (ν) and Beta (β) Sco. Each of these bright stars has a fainter companion slightly less than 1" away, demanding a steady night for you to split them. ▣



ASTRONOMY: THEO COBB

NEWLY DISCOVERED COMET C/2005 E2 (McNaught) should glow around 11th magnitude this month. Don't miss its close pass by the bright globular cluster M55 in Sagittarius.



ASTRONOMY: THEO COBB

COMET 9P/TEMPEL 1 may show lingering effects from its July 4 collision with Deep Impact. If so, its October 1 meeting with open cluster M6 could be outstanding.

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The NexImage takes high power Moon and planet images with any scope and sends them to your computer to view live or print out later.

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Celestron go-to scopes start at a low $279.

$339

80mm Celestron NexStar 80 SLT

You don't need to know the Pleiades from Polaris to find your way around the sky with a **Celestron SLT** go-to telescope. With Celestron SkyAlign technology, just point your SLT at any three of the 50 brightest lights in the sky (3 stars, or 2 stars and a planet), and the SLT will find the planets and over 4,000 deep space objects for you *automatically.* A few anonymous points of light are all you need to find your way around the skies like a pro.

Celestron SLT no-guesswork go-to scopes are available in these sizes:

NexStar 60, 60mm refractor	**$279.00**
NexStar 80, 80mm refractor	**379.00**
NexStar 102, 102mm refractor	**479.00**
NexStar 114, 114mm reflector	**399.00**
NexStar 130, 130mm reflector	**439.00**

Each is complete with two eyepieces, a red dot finder, motor drives, stainless steel tripod, NexStar computer, software to control the scope from your home computer, and more.

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It's easy to find your way around the sky with a GPS-equipped **Celestron CPC** SCT. Just point it at any three of the 50 brightest lights in the sky (3 stars, or 2 stars and a planet or the Moon), and the CPC finds over 45,000 deep space objects for you at the touch of a button.

You don't have to memorize a star chart to use a CPC. The GPS system and a few anonymous lights in the sky are all you need.

Celestron CPC Schmidt-Cassegrains are available in the following sizes:

8" **CPC800**, Starbright coatings	**$1899.00**
8" **CPC800X**, XLT coatings	**1999.00**
9¼" **CPC925**, Starbright coatings	**2349.00**
9¼" **CPC925X**, XLT coatings	**2499.00**
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11" **CPC1100X**, XLT coatings	**2799.00**

Each has all the visual and photographic features you want and need, plus Celestron's best multicoated optics ever.

Big Celestron 11" scopes start at only $1699.

11" Celestron C11S

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Celestron Advanced Series 11" German mount Schmidt-Cassegrains have almost twice the light-gathering of an 8" telescope. They show you more deep space wonders than an 8" SCT on a fork mount – *for about the same price.*

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The C11S and C11S (XLT) have a heavy-duty equatorial mount, adjustable height tripod with 2" steel legs, slow motion controls, setting circles, a 40mm Plössl eyepiece, and a 9 x 50mm finder. Starbright multicoated optics are standard. State-of-the-art Starbright XLT multicoatings on the C11S (XLT) give you an extra 16% light transmission for even brighter images. An optional dual-axis drive is available.

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A binoviewer *with* eyepieces for only $199.

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. . . and 70° super wide angles start at only $59.

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> I ordered a Coronado PST a few weeks back and it's the best $500 I've ever spent. Better than I ever thought it would be. I'm writing to tell you how satisfied I was with your quick, friendly, and well-informed service. Heck, my sales guy really liked telescopes and it showed. I called and ordered a binoviewer today and had the same great service. From now on, I will always call you first. You have earned my trust 100% and I want to thank you!
>
> **Customer Quote of the Month #163**

Award-winning solar observing for the price of an eyepiece!

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A William Optics Petzval-type semi-apo for $448.

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William Optics ZenithStar 66mm semi-apo OTA

Another manufacturer's 4" Petzval-type apo optical tube costs $3600 and is worth it. The **ZenithStar 66 Astro** from **William Optics** has a 66mm Petzval-type multicoated 4-lens objective with an ED glass element for very nearly color-free performance. It costs only $448 and is *more* than worth it.

It comes with a rotatable 2" Crayford focuser, 1/10th wave accuracy 2" star diagonal with a *dielectric* mirror for 99% reflectivity, retractable lens shade, dust caps, and a soft carry case.

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#126 2x for ETX90/105/125	**47.95**
#140 2x 3-element apo	**49.00**
2x 4-element Series 5000	**$159.00**
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Takahashi 2x	**169.95**
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The high-performance **TeleVue** dielectric narrow-band light pollution filters have dropped in price, but you still get the same outstanding image-improving performance.

Their special red blocking technology and polished optical quality BK-7 glass substrates allow brighter, sharper star images without the red fringing seen on most light pollution filters.

The UHC-type narrow band filter is good for all nebula types and instrument sizes.

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Dioptrx lenses eliminate eyeglasses for observing.

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TeleVue Dioptrx astigmatism-correcting accessory lenses attach to the top of TeleVue eyepieces so you don't have to put up with the inconvenience of eyeglasses when you observe. They are available in 0.25 diopter steps from 0.25 to 2.50 diopters.

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Each TeleVue Dioptrx lens is made of multicoated precision-ground optical glass, mounted in an anodized aluminum housing that locks into place on your TeleVue eyepiece.

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Konus Konustart-900 60mm	109^{00}
Konusmotor-70 70mm	149^{00}
Konusmotor-90 90mm	209^{00}
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Deep Impact's daring mission went off without a hitch, although slamming into a comet's nucleus doesn't seem to have excavated a lot of fresh material.

/// BY RICHARD TALCOTT

Blasting the past

In the early morning hours of July 4, giddy, sleep-deprived astronomers marveled at the detail in the best pictures of a comet's nucleus ever captured. NASA's Deep Impact mission had just gone off like clockwork: At 1:52 A.M. EDT, an 820-pound (370 kilogram), washing-machine-size spacecraft slammed into Comet 9n/Tempel 1 at 23,000 mph (37,000 km/h). The impactor snapped pictures down to within seconds of being vaporized in the collision. Meanwhile, a larger flyby spacecraft turned two cameras and one spectrometer toward the comet to study the effects.

The images show features as small as a dozen feet (4m) across on the 3-mile-wide (5 km), 7-mile-long (11 km) nucleus. The comet's dark surface showed circular craters, plains, ridges, plateaus, and even loose debris. Before Deep Impact, scientists had seen three comets up close. The Giotto spacecraft flew past Comet Halley in 1986, Deep Space 1 encountered Comet Borrelly in 2001, and Stardust imaged Comet Wild 2 just last year. Yet none of those missions came as close as Deep Impact did — delivering images nearly 10 times better than any taken before.

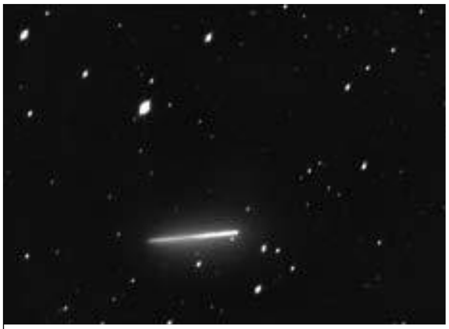
"The final image was taken from a distance of 18.6 miles [30 km] from the comet's surface" — 3 seconds before impact — says Deep Impact principal investigator Michael A'Hearn of the University of Maryland. "When I signed on for this mission, I wanted to get a close-up look at a comet, but this is ridiculous — in a great way."

Tempel 1's surface looks different than Borrelly's or Wild 2's, and those weren't carbon copies of each other either. "We don't understand what this means yet," says A'Hearn. Astronomers hypothesized that the diversity seen in Borrelly and Wild 2 arose from their distinct orbital histories.

Borrelly has a long history of repeated passages by Jupiter, with at least three in the 19th century and two in the 20th. Wild 2 was a long-period comet that never spent much time near the Sun until a fateful pass by Jupiter in 1974. Now, it comes nearly as close to the Sun as Mars every 6.4 years.

Bang, flash, plume

Comets like Tempel 1 consist of ice and dust — "dirty snowballs" as astronomer Fred Whipple described them. They date back to the origin of the solar system some 4.5 billion years ago and have spent most of their lives in the deep freeze at the edge of the solar system.



KITT PEAK VISITOR'S CENTER OBSERVATORY

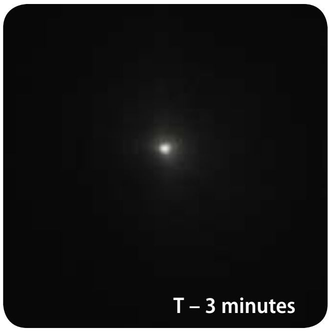
THE COMET BRIGHTENED dramatically at impact. This mosaic of hundreds of images shows the comet (streak) over a 2-hour period centered on impact.

That makes them near-perfect time capsules that hold clues as to how the solar system formed and evolved. Yet most of those clues lie buried beneath a veneer of material altered by long-term exposure to space and sunlight.

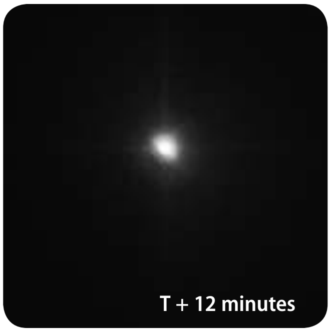
Enter Deep Impact. Following its January 12 launch, the spacecraft traveled 268 million miles (431 million km) in 173 days to meet up with Tempel 1. Twenty-four hours before it encountered the comet, the impactor separated from the flyby craft and maneuvered itself to be run over. Far from the probe ramming the comet, the impact was more akin to flipping a penny in front of an on-rushing freight train (traveling at 23,000 mph).

The impactor struck, then vaporized well below the comet's surface. The blast, equivalent to 4.8 tons of TNT, heated the cometary material to a temperature approaching that of the Sun's surface.

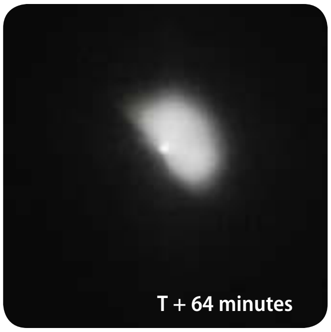
Richard Talcott *is a senior editor of* Astronomy.



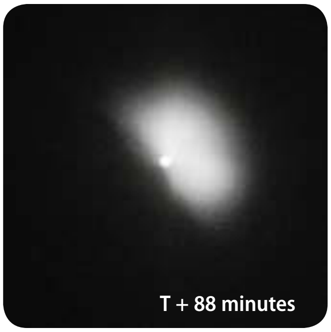
T – 3 minutes



T + 12 minutes



T + 64 minutes



T + 88 minutes

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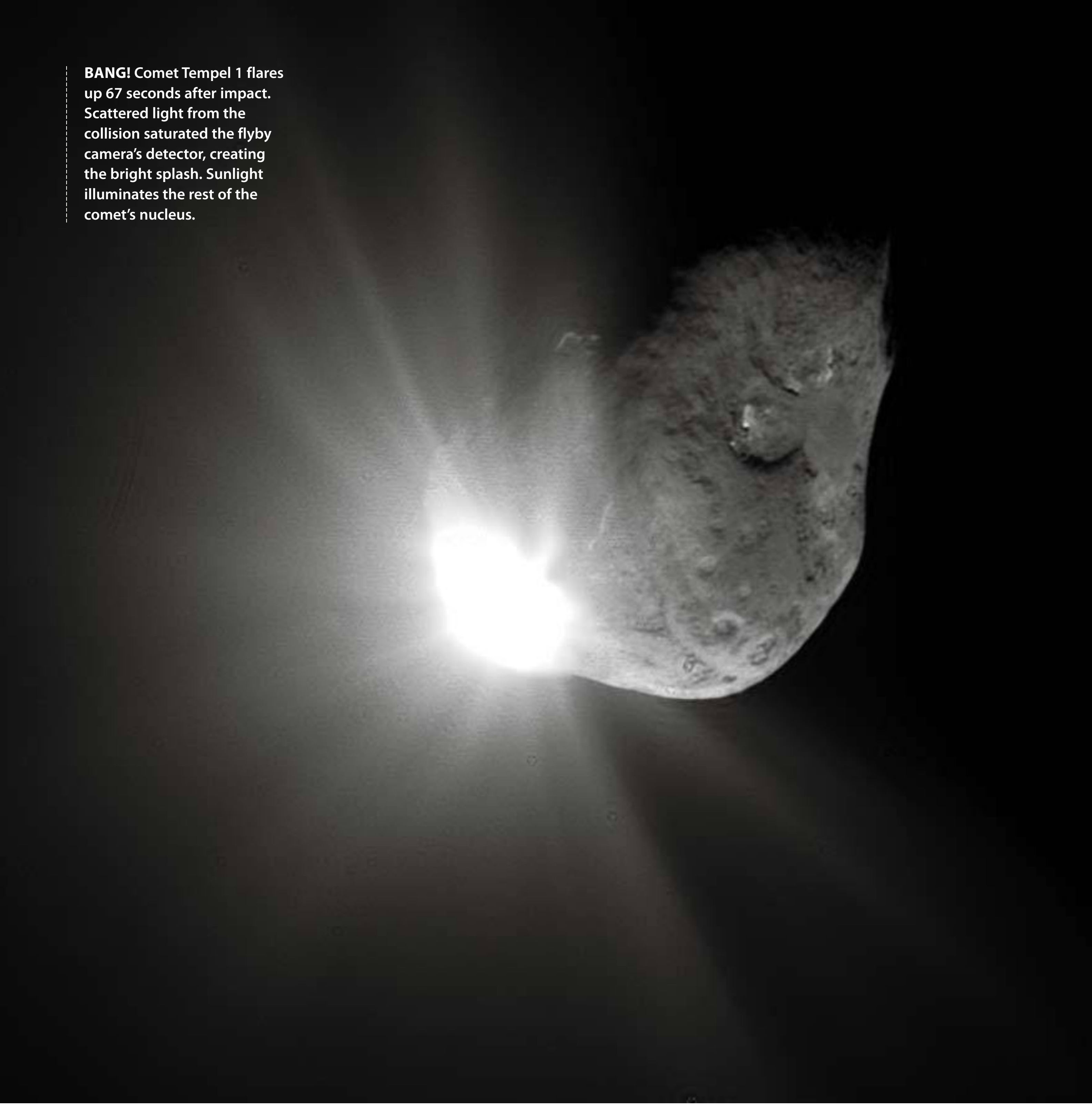
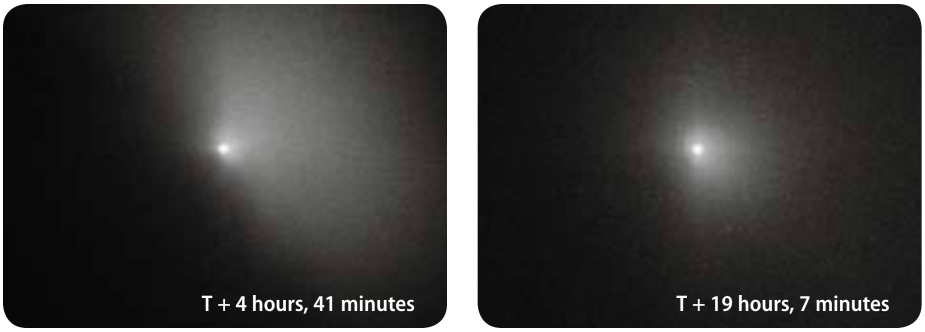
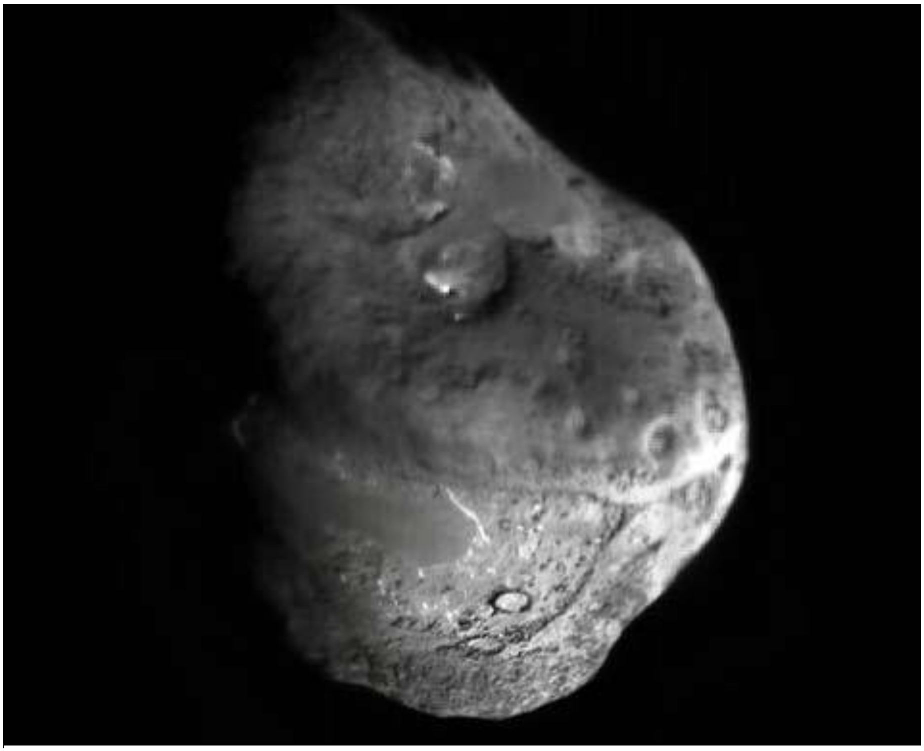


BANG! Comet Tempel 1 flares up 67 seconds after impact. Scattered light from the collision saturated the flyby camera's detector, creating the bright splash. Sunlight illuminates the rest of the comet's nucleus.

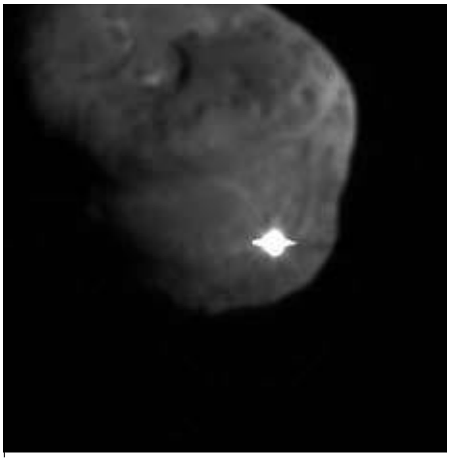


A PLUME ERUPTS from Comet Tempel 1 as the impactor strikes. These Hubble Space Telescope images show the comet from 3 minutes before impact to 19 hours after. NASA, ESA, P. FELDMAN (JHU), AND H. WEAVER (JHUAPL)



NASA/JPL/UMD/FRANCIS REDDY

COMET TEMPEL 1 shows a varied surface, with craters, ridges, and plateaus vying for prominence across its 3-mile-wide (5 km) by 7-mile-long (11 km) nucleus. This is a mosaic created from images returned by the impactor's camera.



NASA/JPL/UMD

SECONDS AFTER IMPACT, incandescent debris explodes from the impact site on Comet Tempel 1's nucleus.

A brilliant flash illuminated the scene within the first second as the fireball of vaporized impactor and comet material shot skyward at 11,000 mph (18,000 km/h). The fireball's immense plume put on a show for a worldwide audience thanks to images taken by telescopes both in space and on the ground.

"The major surprise was the opacity of the plume the impactor created and the light it gave off," says A'Hearn. "That suggests the dust excavated from the comet's surface was extremely fine, more like talcum powder than beach sand." Deep Impact showed the popular image of a comet — an object like an ice cube with some dirt thrown in — certainly does not apply to Tempel 1.

How can an object made with material the strength of talcum powder survive the ravages of the solar system for billions of years? "You have to think of it in the context of its environment," says Deep Impact scientist Peter Schultz of Brown University. "olis city-size object is floating around in a vacuum. The only time it gets bothered is when the Sun cooks it a little or someone slams an 820-pound wake-up call at it at 23,000 mph."

How deep an impact?

The vast plume may have obscured one of the mission's prime objectives, however — examining the impact crater. The science team didn't expect it to be easy to find. They knew cometary debris would shroud the view to some extent.

But after 3 weeks of concerted efforts, the team had yet to pinpoint the crater. Still, with about 4,500 images and several gigabytes of data sent back by the spacecraft, it will take months to analyze them all.

Before the impact, astronomers thought the crater could be as small as a house or as big as a football stadium, and anywhere from two to 14 stories deep. The best estimate of how much material was released comes from X-ray observations made with NASA's Swift satellite.

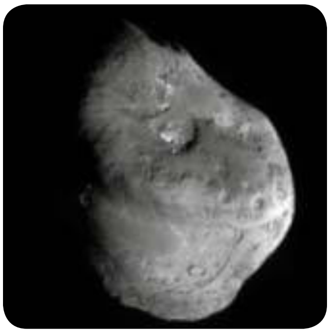
As the newly liberated material made its way into the comet's thin atmosphere, or coma, the high-energy solar wind excited the material and caused it to glow in X rays.

NASA/JPL/UMD

30 MINUTES BEFORE IMPACT, the impactor's camera viewed Comet Tempel 1. The brightness has been enhanced to show jets of material emanating from the comet's nucleus.

NASA/JPL/UMD

WITH 6 MINUTES TO GO, the camera onboard the impactor captured detail across the comet's entire nucleus.

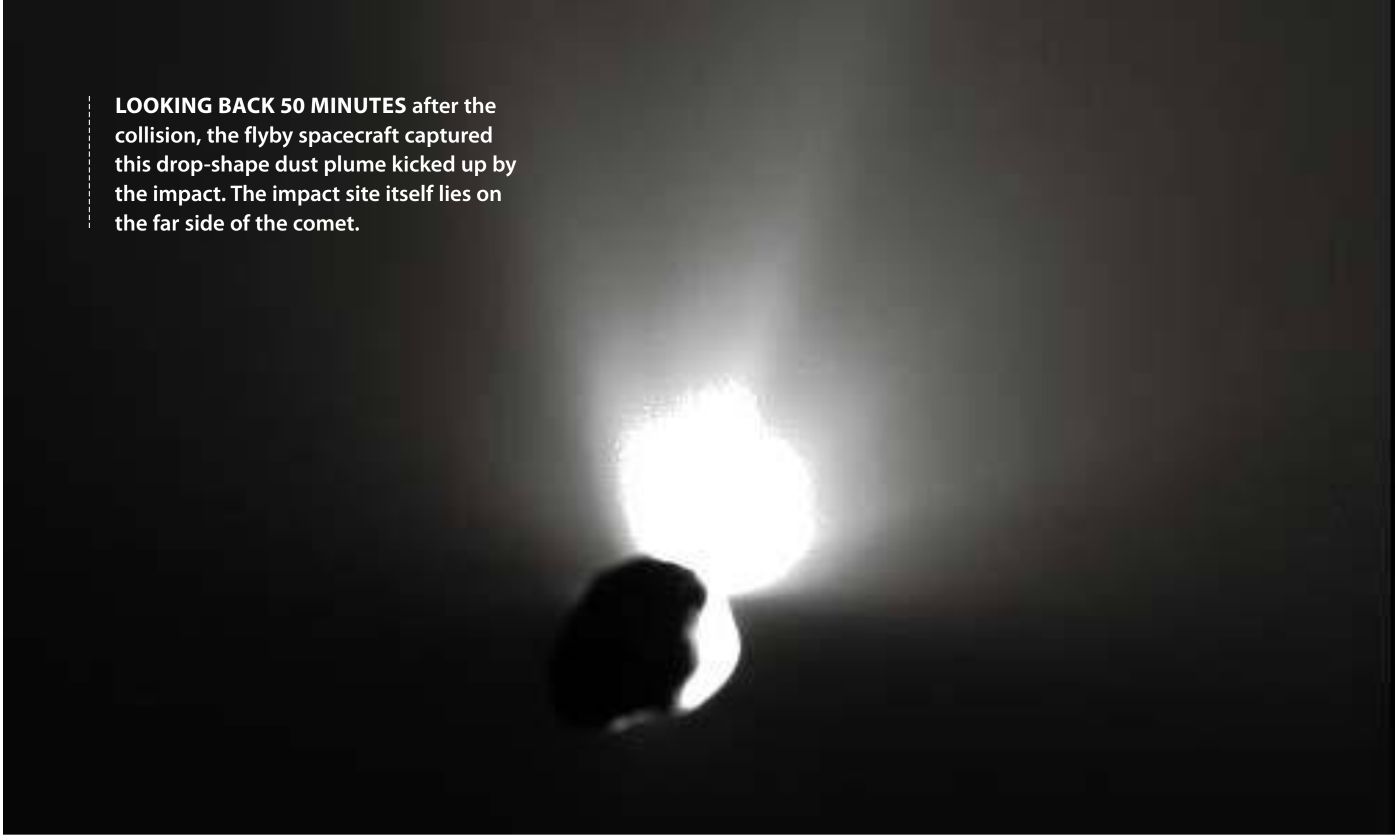


NASA/JPL/UMD

5 MINUTES OUT, the impactor recorded the whole nucleus for the last time. The probe crashed between the two dark-rimmed craters near the comet's center and bottom.

NASA/JPL/UMD

ONLY 90 SECONDS AWAY, the looming comet bears down on the massive, 820-pound (370 kg) spacecraft.



LOOKING BACK 50 MINUTES after the collision, the flyby spacecraft captured this drop-shape dust plume kicked up by the impact. The impact site itself lies on the far side of the comet.

NASA/JPL/UMD

Based on preliminary analysis, Swift team member Paul O'Brien of the University of Leicester in England estimates the blast excavated tens of thousands of tons of material, enough to bury a football stadium under 30 feet (10m) of dust.

Despite the initial fireworks, the impact apparently didn't alter Tempel 1's overall behavior. In the first few days, images taken with the European Southern Observatory's Very Large Telescope in Chile showed the new plume expanding at several hundred mph. This structure slowly diffused away, however, and within 10 days, the comet had returned to its appearance prior to impact.

Astronomers expected the impact would dig deep enough to release pristine material from the birth of the solar system. But that may not have come to pass either. "It's pretty clear this event did not produce a gusher," says Gary Melnick of the Harvard-Smithsonian Center for Astrophysics, principal investigator on NASA's Submillimeter Wave Astronomy Satellite. The satellite monitored Tempel 1 during and after the impact, but failed to see a big increase in water vapor and other gases.

That may force astronomers to revise their ideas about what lies beneath the surfaces of short-period comets like Tempel 1. After being bombarded by solar radiation during repeated trips around the Sun, such comets naturally build up a thick skin. Before Deep Impact, theorists thought this veneer might extend several feet. But if preliminary results hold up, the altered surface may be much thicker — and the pristine material locked away much deeper.

A future encounter?

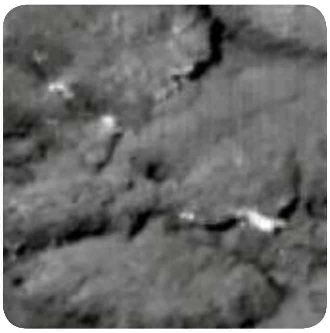
The first 3 weeks after the collision tell only part of the story, of course. As the Deep Impact scientists pore over the data, they'll create higher-resolution images and more-detailed spectra. The mysteries still surrounding Tempel 1 should yield slowly to the ongoing scrutiny.

And Deep Impact may write another chapter in its comet story. Mission planners hope to send the flyby spacecraft on to a second target — Comet 85P/Boethin. "NASA has agreed to preserve the option of the extended mission," says A'Hearn.

The team fired the spacecraft's thrusters July 20, which will send Deep Impact back to Earth in December 2007. The maneuver leaves open the possibility of using a gravity assist to boost the spacecraft toward Boethin. Although there's no second impactor to create a new fireworks display, another comet flyby can only help astronomers in their quest to understand these relics of the solar system's birth. ■

NASA/JPL/UMD

WITH 60 SECONDS TO GO, the impactor's camera captures intriguing light and dark markings.



NASA/JPL/UMD

30 SECONDS OUT, Comet Tempel 1's nucleus is still nearly 200 miles away but approaching at 23,000 mph (37,000 km/h).

NASA/JPL/UMD

JUST 20 SECONDS REMAINED in the life of the impactor when it took this image of the comet's nucleus, which contains the impact site.

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Ask Astro

Making new constellations, stellar alphabet, parallax view

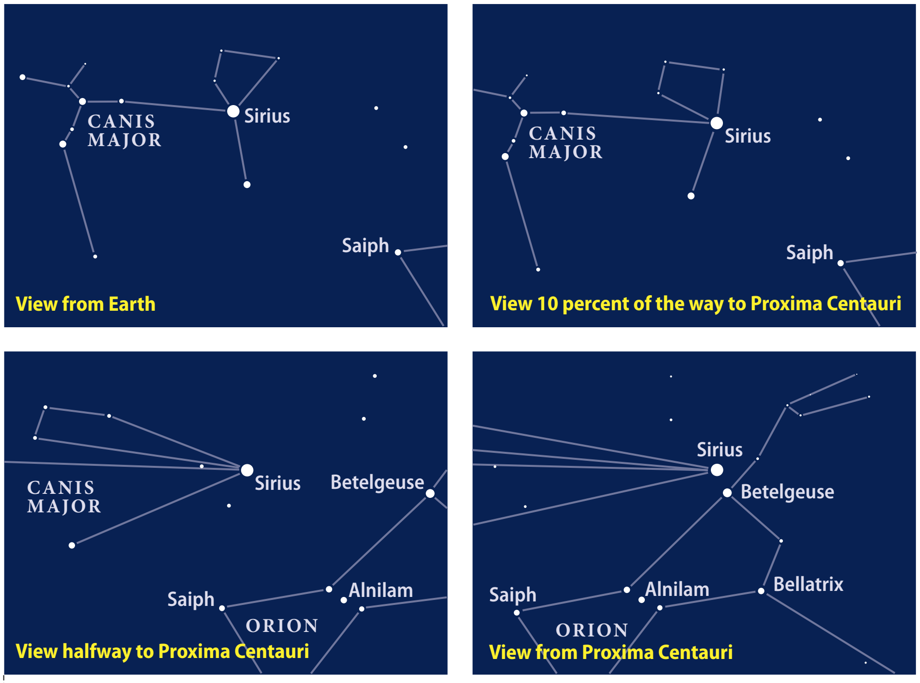
MAKING NEW CONSTELLATIONS

If my daughter is the first to set foot on Mars, will she and her crewmates have the honor of creating and naming new constellations? — **ROB BIGNELL,** IOWA CITY, IOWA

Unfortunately, your daughter will have to travel much farther than Mars to notice change in the shape of constellations. The stars are so distant that, even from cold Pluto, the constellations will look the same as they do here on Earth. She would have to travel more than 77 times Earth's distance from the Sun (for a distance of 7.2 billion miles) before noticing even the slightest change in the position of Proxima Centauri, which lies 4.22 light-years away and is the closest neighboring star.

Nearby stars would be the first to show a change against the more distant starry background. For example, let's take an imaginary journey to Proxima Centauri. On the way, we'll check the position of Sirius, Canis Major's brightest star — and the brightest in our sky. Sirius lies just 8.6 light-years away, which is one reason it's so prominent.

We'd see a significant shift (parallax) in Sirius' position after traveling only 10 percent of the way to Proxima. But this distance is enormous compared to what we deal with in our solar system: It's nearly 27,000 times Earth's distance from the Sun. Our fastest spacecraft would take about 3,900 years to reach this far.



ASTRONOMY: JAY SMITH

A TRAVELER TO THE NEAREST STAR could watch Sirius drift northwest toward Orion as the journey progressed. Nearby stars like Sirius will show the most dramatic shifts when astronauts traverse such distances, but within the solar system — even beyond Pluto — the constellations won't appear to change.

Continuing on our imaginary journey, and neglecting the limits of current space technology, Sirius proceeds to glide across the sky until Canis Major is no longer recognizable. By the time we arrive at Proxima Centauri, Sirius lies within 1.7° of Betelgeuse, the star marking Orion's right shoulder. — **BILL COOKE,** MARSHALL SPACE FLIGHT CENTER, HUNTSVILLE, ALABAMA

STELLAR ALPHABET

What is the origin of the letters used in star classification? Why didn't astronomers use ABCD?

— **J. HALDIMAN,** CHICAGO

Stellar spectral types originally followed alphabetical order. But as astronomers observed more stars and obtained more detailed spectra, they consolidated some categories and re-ordered the remaining ones. This left seven basic stellar types, designated OBAFGKM, which generations of astronomers and science-fiction readers have learned through the mnemonic "Oh, Be A Fine Girl (or Guy), Kiss Me."

In 1866, Angelo Secchi, a Jesuit astronomer working at the Vatican Observatory, surveyed some 4,000 stars and classified them by the visual appearance of their spectra. He divided stars into four broad, numbered categories based on common spectral features.

Henry Draper, an American physician, amateur astronomer, and pioneer in photography, recorded the first image of a stellar spectrum (Vega) in August 1872. After Draper's death in 1882, his wife Anna established a memorial fund to support the development of photographic techniques in astronomy. This fund paid for the

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/// SPECTRAL CLASSES

Class	Surface temperature	Spectral characteristics	Example
O	28,000 – 50,000 K	Ionized helium; weak hydrogen lines	Naos, Alnilam
B	10,000 – 28,000 K	Neutral helium; stronger hydrogen lines	Rigel, Spica
A	7,500 – 10,000 K	Strong hydrogen lines, plus magnesium, calcium, iron	Vega, Sirius
F	6,000 – 7,500 K	Weaker hydrogen lines, singly ionized and neutral metals	Canopus, Procyon
G	4,900 – 6,000 K	Ionized calcium strongest; hydrogen weaker than F	Sun, Capella, Alpha Centauri A
K	3,500 – 4,900 K	Neutral metal lines predominate	Arcturus, Aldebaran
M	2,000 – 3,500 K	Strong in neutral metals and molecules	Betelgeuse, Antares, red/brown dwarfs
L	1,300 – 2,000 K	Neutral alkali metals, hydrides	2M1507 (brown dwarf)
T	Less than 1,300 K	Methane and sodium absorption	Epsilon Indi ba (brown dwarf)

The tinted background illustrates star color for each spectral type.

largest effort to classify stellar spectra attempted at the time — and the one that established the peculiar spectral alphabet we have today.

Between 1886 and 1897, Edward C. Pickering of Harvard College Observatory led a survey in which stellar spectra were photographed and classified by the thousands. Initially, Pickering assigned each spectral type a letter of the alphabet based on the strength of the star's hydrogen, with A being the strongest. The result of this monumental effort, the *Henry Draper Catalogue*, was published between 1918 and 1924 and classified 225,300 stars; later extensions brought the total to 359,083.

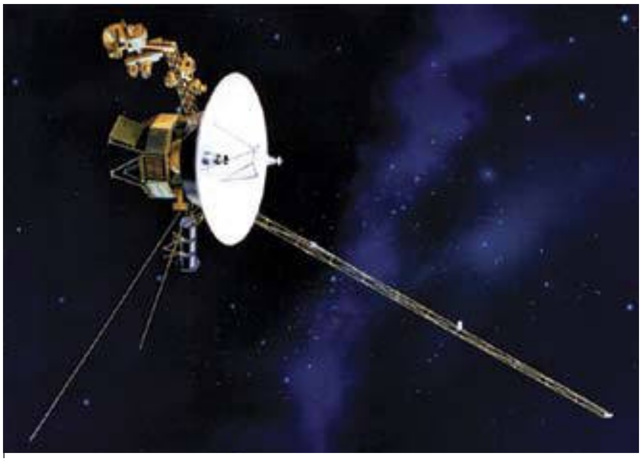
Under Pickering's supervision, his coworkers — particularly Williamina Fleming, Antonia Maury, and Annie Jump Cannon — gradually sorted out spectra, rearranging and combining some of the original categories. One motivation was to organize spectra so they created smooth transitions between different types. The final order actually reflects the surface temperatures of stars, with O stars being the hottest, but the Harvard astronomers didn't realize it at the time. — **FRANCIS REDDY,** ASSOCIATE EDITOR

PARALLAX VIEW

Has anyone used Voyager spacecraft images to measure stellar parallax? — **GLENN PFEFFER,** PLANO, TEXAS

No, but it was considered. The reason parallax measurements weren't taken with Voyager or any other interplanetary spacecraft is simply that astronomers can do better from the ground or with dedicated satellites like Hipparcos in low Earth orbit.

The cameras aboard the Voyager spacecraft provide an image scale such that a single picture element, or pixel, spans about 2" on the sky (1" is $^{1}/_{3,600}$ of a degree). Image-processing software could improve this resolution by a factor of 4, so, in principal, the Voyager cameras could measure a change in the position of a star as small as 0.5".

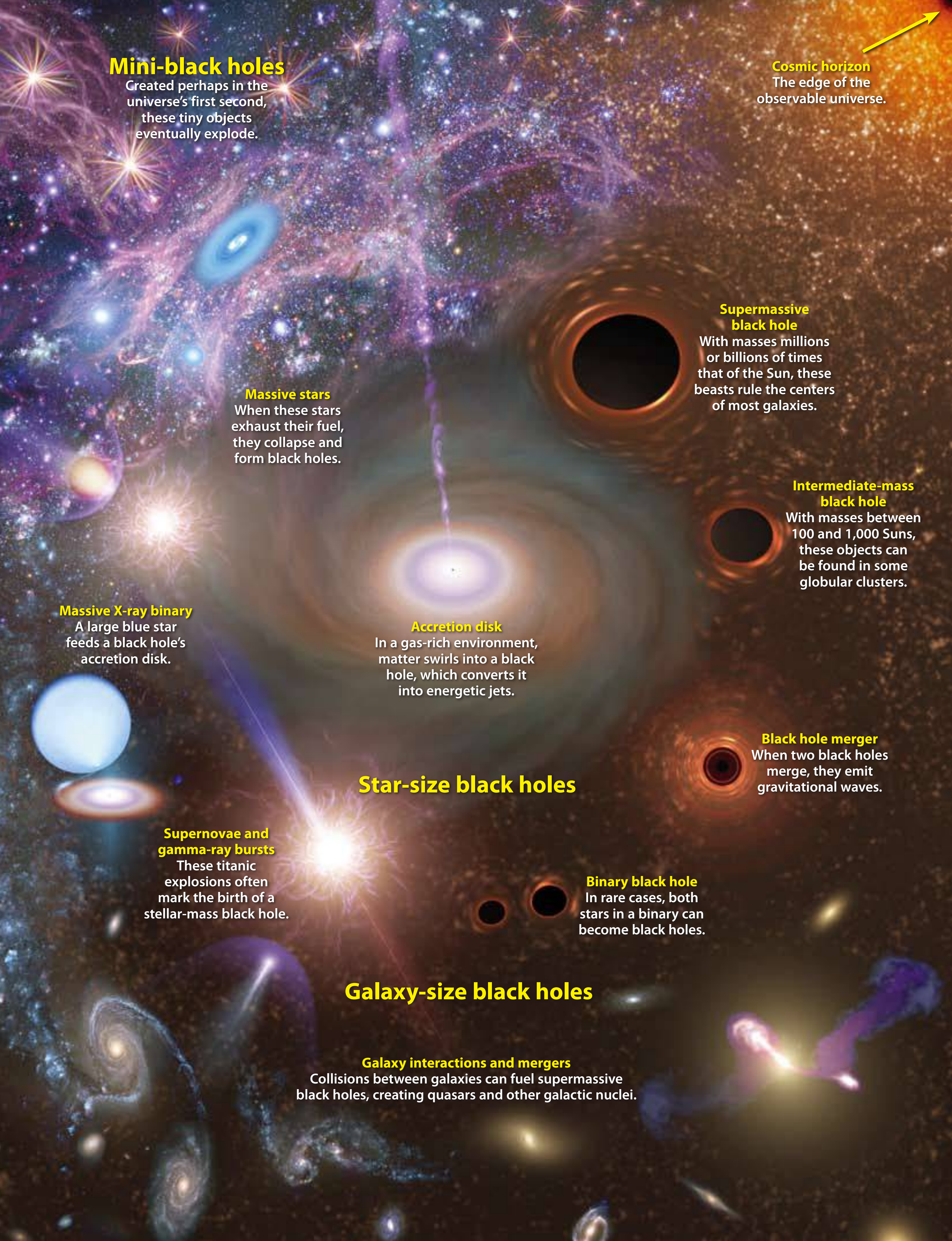

NASA/JPL

VOYAGER 1 AND 2 IMAGES could have been used to measure stellar distances, but ground-based telescopes and Earth-orbiting satellites are far more precise.

A couple of decades ago, the Voyagers could've provided astronomers with a baseline of 30 astronomical units (1 AU equals the Earth-Sun distance) and might have been able to measure the distances of stars out to 195 light-years. I say "might" because the vidicon cameras had a fairly narrow dynamic range and problems with distortion. In the words of a colleague at the Jet Propulsion Laboratory in Pasadena, California, who provided me with most of this information, "It would've been really tough to do."

Contrast this with modern CCD ground-based parallax measurements, or those made by the Hipparcos satellite. Using these methods, astronomers can measure parallaxes as small as 0.001", which allows them to determine stellar distances out to 3,260 light-years. Theoretically, this is more than 15 times better than we could have done with Voyager.

There's no reason in principal that interplanetary spacecraft can't be used to measure stellar distances, provided they're equipped to do so. A while back there was some discussion of sending two identical spacecraft in opposite directions from Earth to do exactly this. The concept didn't get far, in part because parallax measurements don't possess a big "glamour factor." As for the Voyagers, their cameras have been turned off and key camera-control software has been deleted. Their potential for providing such data has ended. — **BILL COOKE,** MARSHALL SPACE FLIGHT CENTER, HUNTSVILLE, ALABAMA



Mini-black holes

Created perhaps in the universe's first second, these tiny objects eventually explode.

Cosmic horizon
The edge of the observable universe.

Supermassive black hole
With masses millions or billions of times that of the Sun, these beasts rule the centers of most galaxies.

Massive stars
When these stars exhaust their fuel, they collapse and form black holes.

Intermediate-mass black hole
With masses between 100 and 1,000 Suns, these objects can be found in some globular clusters.

Massive X-ray binary
A large blue star feeds a black hole's accretion disk.

Accretion disk
In a gas-rich environment, matter swirls into a black hole, which converts it into energetic jets.

Black hole merger
When two black holes merge, they emit gravitational waves.

Star-size black holes

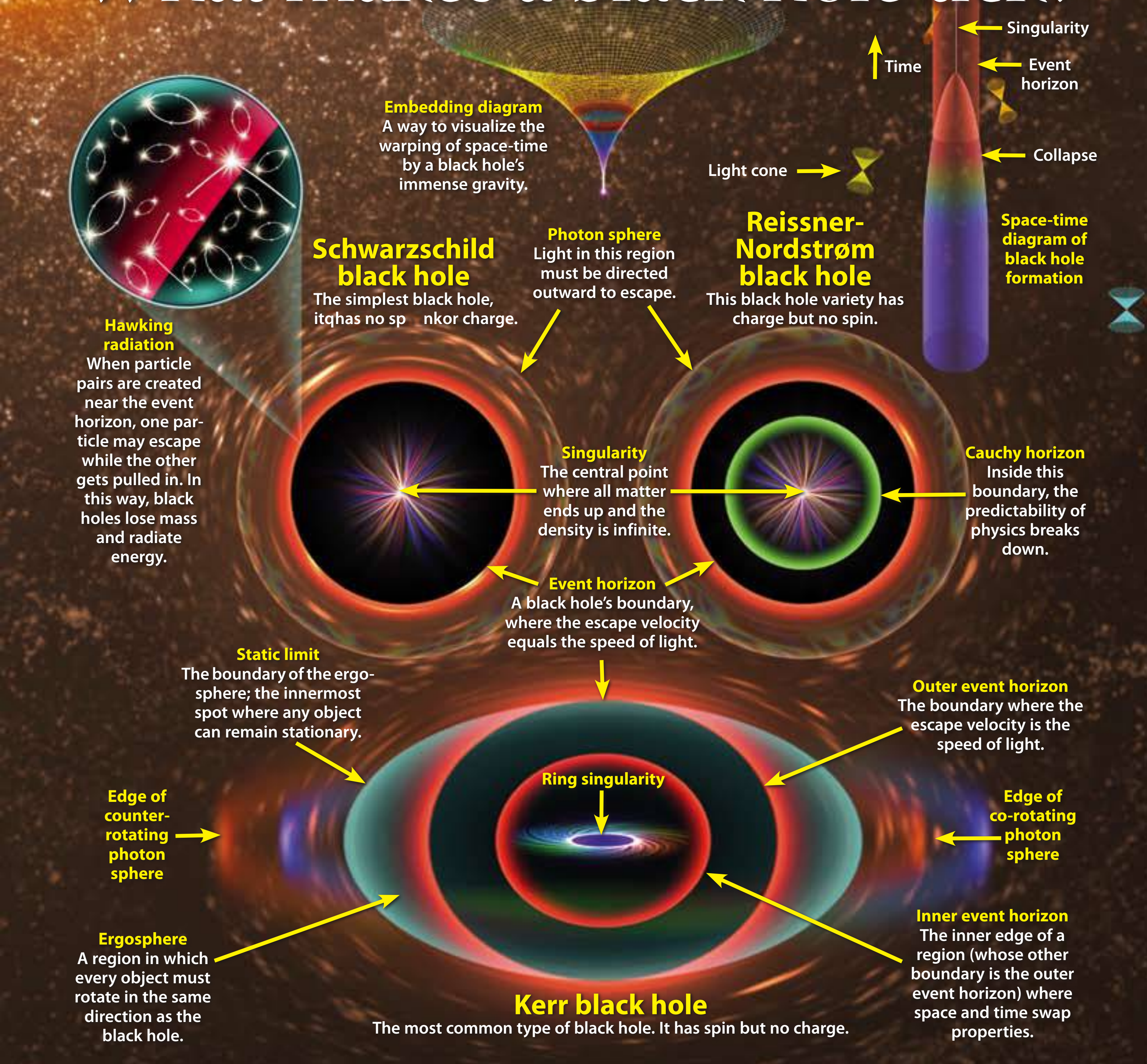
Supernovae and gamma-ray bursts
These titanic explosions often mark the birth of a stellar-mass black hole.

Binary black hole
In rare cases, both stars in a binary can become black holes.

Galaxy-size black holes

Galaxy interactions and mergers
Collisions between galaxies can fuel supermassive black holes, creating quasars and other galactic nuclei.

What makes a black hole tick?



Embedding diagram
A way to visualize the warping of space-time by a black hole's immense gravity.

Time

Singularity

Event horizon

Collapse

Light cone

Space-time diagram of black hole formation

Hawking radiation
When particle pairs are created near the event horizon, one particle may escape while the other gets pulled in. In this way, black holes lose mass and radiate energy.

Schwarzschild black hole
The simplest black hole, itqhas no sp nkor charge.

Photon sphere
Light in this region must be directed outward to escape.

Reissner-Nordstrøm black hole
This black hole variety has charge but no spin.

Singularity
The central point where all matter ends up and the density is infinite.

Cauchy horizon
Inside this boundary, the predictability of physics breaks down.

Event horizon
A black hole's boundary, where the escape velocity equals the speed of light.

Static limit
The boundary of the ergosphere; the innermost spot where any object can remain stationary.

Outer event horizon
The boundary where the escape velocity is the speed of light.

Ring singularity

Edge of counter-rotating photon sphere

Edge of co-rotating photon sphere

Ergosphere
A region in which every object must rotate in the same direction as the black hole.

Inner event horizon
The inner edge of a region (whose other boundary is the outer event horizon) where space and time swap properties.

Kerr black hole
The most common type of black hole. It has spin but no charge.

Long a playground for theorists, black holes now have stepped into reality.

/// BY RICHARD TALCOTT; ILLUSTRATION BY ADOLF SCHALLER

Imagine an object so massive and so compact that its gravity won't let light escape. That's exactly what Einstein's general theory of relativity predicts, and what physicist Karl Schwarzschild first described in detail in 1916. And while decades of scientists thought the idea a flight of fancy — an intriguing concept that had little chance of existing in nature — a few held out hope that such exotic objects might exist.

In the 1960s, the tide began to turn. Physicist John Wheeler coined the name "black hole," and astronomers started discovering extraordinary objects — massive but invisible binary star companions and brilliant quasars, to name two — that were hard to explain any other way. Eventually, most scientists concluded that as strange and wonderful as black holes may seem, these exotic objects exist throughout the cosmos. ◼

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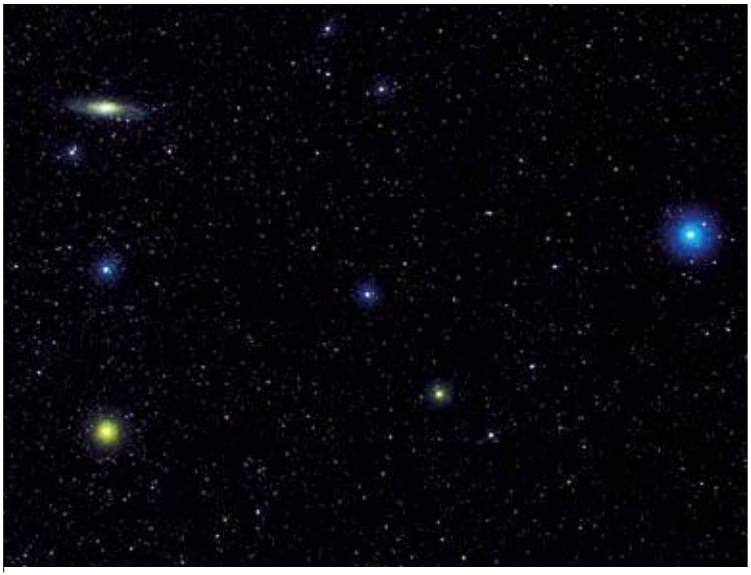
GALACTIC ASTRONOMY

The Andromeda Galaxy offers a rich history of discovery, folklore, and science.

/// BY RAYMOND SHUBINSKI

Hitch a ride on a cosmic spiral

Imagine light departing a galaxy some 2.5 million years ago, and hitting your eye, finally, tonight. With the Andromeda Galaxy (M31), that's what you get — a light show older than the human species. But this old light still dazzles people at star parties.


BILL AND SALLY FLETCHER

BOTH THE ANDROMEDA GALAXY (M31) and the bright stars of the constellation Andromeda the Maiden are easy to see in this image, made with a Pentax 6x7 camera, a 90mm lens at f/5.6, and Kodak 400 PPF film. The imagers applied a diffusing filter, which expands the bright stars, for part of the exposure. The filter doesn't affect faint stars and deep-sky objects. Blue Alpheratz (Alpha [α] Andromedae) sits to the far right, while yellowish Mirach (Beta [β] Andromedae) shines at the bottom left.

Usually, people ask questions like, "How can astronomers determine the vast distances to different galaxies?" The Andromeda Galaxy has played a central role in answering such questions, and the answers helped build our image of the universe.

Mythic beginnings

The story of Andromeda is one of the beot-known, thanks in part to Hollywood. The 1981 movie *Clash of the Titans* retells the story of the Greek hero Perseus.

The gods gave Perseus some great gifts, and he was itching to try them out. So off he went on winged sandals to an island where the fearsome Gorgon Medusa had a nasty habit of turning heroes to stone with just a glance. Having hair made of live snakes probably didn't help her mood much.

Perseus used the reflection in his shield to hunt down Medusa and lop off her head with one swing of his sword. Snakes still squirming, Perseus tossed the head in a magic bag and flew off.

On his way home, he saw beautiful Andromeda chained to rocks on the sea coast. Perseus also saw a sea monster, Cetus, who was about to have the fair maiden for a snack.

Cetus was too huge for Perseus to kill, magic sword or not. Thinking fast, Perseus swept down and pulled Medusa's head from the bag, turning Cetus to stone. Shortly thereafter, Andromeda and Perseus wed.

Can you see me?

Early astronomers were charmed by the beauty of the constellation Andromeda and mystified by the smudge of light it contains. The smudge became known as the Great Nebula (cloud) in Andromeda because neither the human eye nor early telescopes could resolve this object.

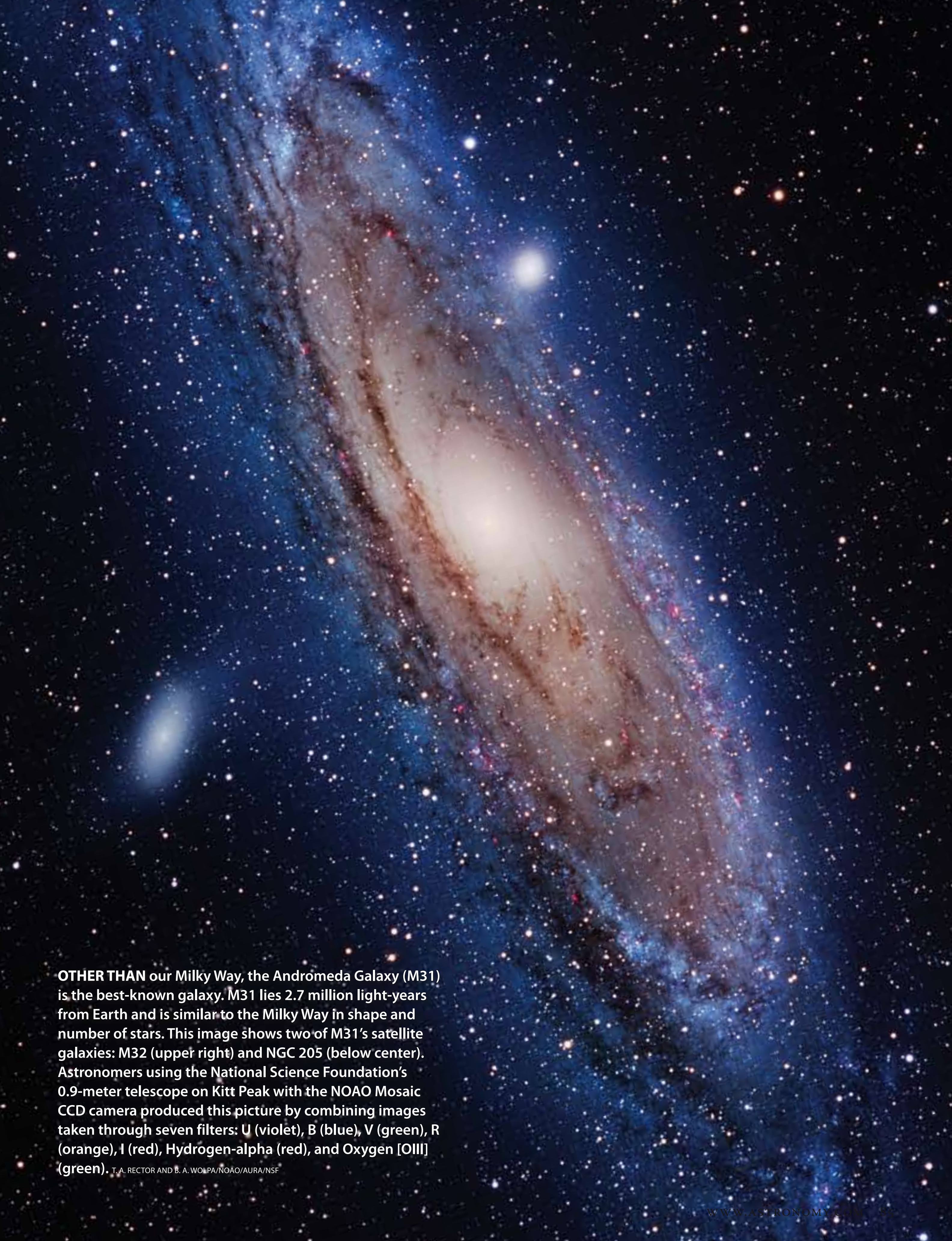
For the majority of amateur astronomers, M31 is the most distant object visible with the unaided eye. Even under the best sky conditions, without binoculars or a telescope, you can expect to see an elongated, fuzzy patch about 1° across. That's twice the diameter of the Full Moon.

In the early 1950s, French astronomer Robert Jonckhere used binoculars to measure the visual size of the Andromeda Galaxy. He found its extent to be roughly 5° by 1°. The currently accepted length is somewhat less. Still, it's not surprising that skywatchers noted this object long before the telescope was invented. Pre-telescopic observers had one big advantage — a dark sky. The Andromeda Galaxy's apparent magnitude is 3.4, and a sharp-eyed observer can detect objects down to 6th magnitude.

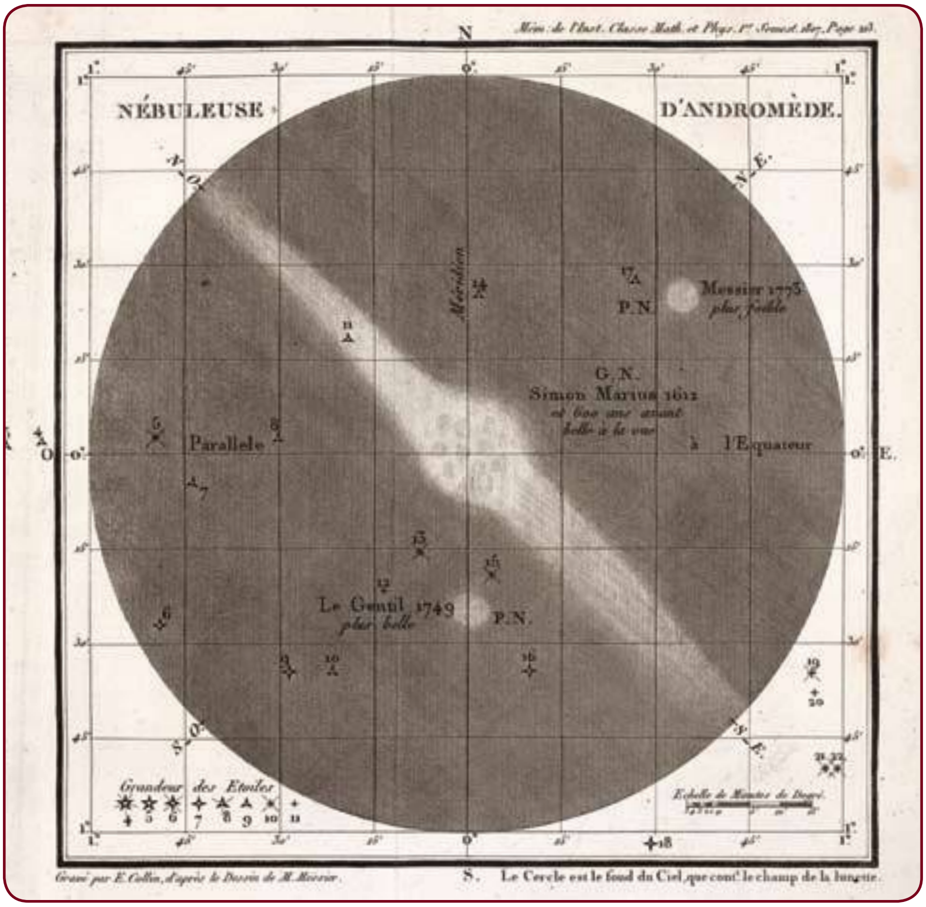
Historical notations

In the 10th century, the world's best scientists lived in Persia. Without these Islamic thinkers, much of ancient Greek knowledge would have been lost. Islamic astronomers of that time also were carrying out important work of their own. In 964, Abd-al-Rahman Al Sufi published his *Book of the Fixed Stars*. He used Ptolemy's *Almagest* as a basis to create his own thousand-star catalog.

Among other contributions, Al Sufi correlated Greek and Arabic star names, giving



OTHER THAN our Milky Way, the Andromeda Galaxy (M31) is the best-known galaxy. M31 lies 2.7 million light-years from Earth and is similar to the Milky Way in shape and number of stars. This image shows two of M31's satellite galaxies: M32 (upper right) and NGC 205 (below center). Astronomers using the National Science Foundation's 0.9-meter telescope on Kitt Peak with the NOAO Mosaic CCD camera produced this picture by combining images taken through seven filters: U (violet), B (blue), V (green), R (orange), I (red), Hydrogen-alpha (red), and Oxygen [OIII] (green). T. A. RECTOR AND B. A. WOLPA/NOAO/AURA/NSF


Mém. de l'Inst. Classe Math. et Phys. 1er Semest. 1807, Page 218.
N
NÉBULEUSE
D'ANDROMÈDE.
N.O.
N.E.
Méridien
P.N.
Messier 1773
plus foible
G.N.
Simon Marius 1612
et 600 ans avant
belle à la vue
Parallele
à l'Equateur
O.
E.
Le Gentil 1749
plus belle
P.N.
S.O.
S.E.
Grandeur des Etoiles
Echelle de Minutes de Degré.
S.
Gravé par E. Collin, d'après le Dessin de M. Messier.
Le Cercle est le fond du Ciel, que cont.t le champ de la lunette.

THAT'S NO COMET! French astronomer and comet-hunter Charles Messier made the Andromeda Galaxy number 31 in a catalog he created to help others avoid mistaking stationary celestial objects as comets. Messier first cataloged the Andromeda Galaxy August 3, 1764. In the *Connaissance des Temps* for 1807, Messier sketched the positions and apparent sizes of M31, M32, and NGC 205.

LINDA HALL LIBRARY OF SCIENCE, ENGINEERING, AND TECHNOLOGY

us some of the lively nomenclature we use on star charts today. In his drawing of the constellation of Andromeda, Al Sufi marked an object he called the "Little Cloud" just above the stars Beta (β) and Nu (ν) Andromedae. Al Sufi's little cloud was the Andromeda Galaxy.

After the telescope was invented in Holland in 1608, clever minds turned the new device skyward. While observing with his telescope December 15, 1612, German astronomer Simon Marius "discovered" an elongated object in Andromeda. Marius was unaware of Al Sufi's work but gets credit for the first telescopic observation of the galaxy. To Marius, the galaxy looked like "the light of a candle shining through horn." It would be many years before telescopes improved enough to resolve more than a flicker of light from M31.

By the 17th century, finding the great Andromeda nebula had become something of a game. In 1654, Italian astronomer Giovanni Batista Hodierna published a catalog of 40 nonstellar objects. His book lists a nebula in Andromeda, but the publication was not widely circulated. Hodierna must have had a keen eye to find such diffuse objects as the Andromeda Galaxy using a simple Galilean telescope. In *Star Names and their Meanings* (1899), Richard H. Allen says the nebula appeared on a Dutch star map in 1500, although he doesn't mention who created the map or his source.

Englishman Edmund Halley published *An Account of several Nebulae or lucid Spots like Clouds, lately discovered among the Fixed Stars by help of the Telescope*. His paper appeared in the Royal Society's publication, *Philosophical Transactions*, for 1716. Halley does not lay claim to M31's discovery but ascribes it to French astronomer and priest Ismael Bullialdus. Bullialdus observed the nebula in 1661 and mentions it in his work. He says the nebula had been observed 150 years earlier.

Halley also must have observed it with a telescope. He describes the nebula as "a pale cloud, and [it] seems to emit a radiant beam into the northeast." Halley points out the nebula seemed to glow and shine without stars.

The 31st M

Charles Messier, the man French King Louis XV called the "Comet Ferret" finally put the Andromeda Nebula on the map. Messier became fascinated with comets when, in 1744, a spectacular one appeared above the European sky.

Seven years later, Messier went to work in Paris as assistant to the Navy's astronomer, Joseph Nicolas Delisle. As Messier hunted for comets, he would occasionally find objects that appeared comet-like but didn't move. He compiled a catalog of objects that every observer is familiar with today. The Andromeda Nebula — the 31st object on his list — is designated M31. Messier produced a drawing that clearly shows the elongated nature of this object, a perennial favorite at autumn star parties.

On December 7, 1781, William Herschel was elected into England's Royal Astronomical Society and was presented with a copy of Messier's *Catalog of Nebulae and Star Clusters*. Herschel had electrified the world with his discovery of Uranus in March of the same year, thus doubling the size of the solar system. Herschel was so intrigued with the catalog that he completed a systematic survey of Messier's objects and, eventually, the entire sky. By 1783, Herschel was using a reflecting telescope with an 18.7-inch mirror. He wanted to map the shape of the universe by determining star density across the sky. He came to some interesting conclusions about Messier's nebula 31.

From his star counts and his study of Messier's list, Herschel deduced the Milky Way is shaped like a broad, flat disk. He placed the Sun and planets at the disk's center. He also speculated M31 might be a star system beyond the Milky Way.

Herschel's dimensions fell far short of reality, but he was getting closer to the truth. He followed the lead of German philosopher Immanuel Kant, who speculated some nebulae might be star systems beyond our own, or "island universes."

New tools, new discoveries

As the 19th century dawned, technology began to catch up with philosophers and astronomers. Early in the century, German physicist Joseph von Fraunhöfer was mapping absorption lines in the Sun's spectrum. By mid-century, English astronomer William Huggins was using a spectroscope to study Messier objects.

Huggins found line spectra in planetary nebulae such as the Dumbbell Nebula (M27) and the Ring Nebula (M57) indicating vast amounts of gas. When he turned the spectroscope on M31 and its companion, M32, he found a continuous spectrum similar to the Sun's and that of other stars. This indicated objects such as M31 were composed of unresolvable stars.

In 1843, William Parsons, third earl of Rosse, rolled out the big gun in Ireland. William Herschel eventually built a reflecting telescope with a 48-inch mirror. The scope was ungainly and hard to maneuver, so it saw little use. Undeterred, Lord Rosse built an even larger telescope with a mirror 72 inches across — the world's largest. He mounted it in a wooden tube between two stone walls and, using a series of pulleys, hoisted the scope like a ship's rigging.

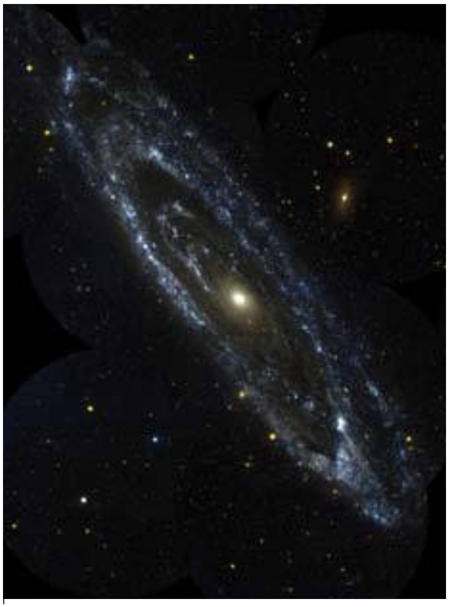
Using the "Leviathan of Parsonstown," as his scope was called, Rosse made incredibly detailed drawings of nebulae, including M31 and the Whirlpool Galaxy (M51), which we now know is a face-on spiral galaxy. Unfortunately, Rosse's results still did not reveal the nature of these objects.

English amateur astronomer Isaac Roberts captured a photograph of the Andromeda nebula in 1887 that showed — for the first time — the object's spiral structure clearly. At the time, astronomers had begun considering the idea that spiral nebulae were planetary systems in the act of formation. Roberts' excellent photograph shattered that theory.

In 1907, a report claimed to have measured a parallax shift for M31 giving an absurdly short distance of 19 light-years. The secret to the true distance of M31, however, was hidden in its starlight.

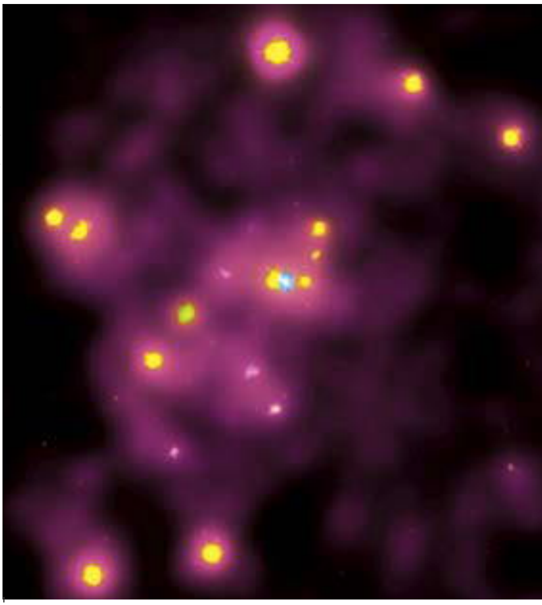
In 1885, a supernova was seen in M31. Sixteen years later, a nova in the constellation Perseus provided the basis for comparing the light outputs from these events. Unfortunately, the supernova of 1885 and the nova of 1901 were not the same type of event. Still, the comparison gave a distance to M31 of 1,600 light-years, which moved it well beyond our local region.

Raymond Shubinski *is the director of the East Kentucky Science Center in Prestonsburg, Kentucky.*



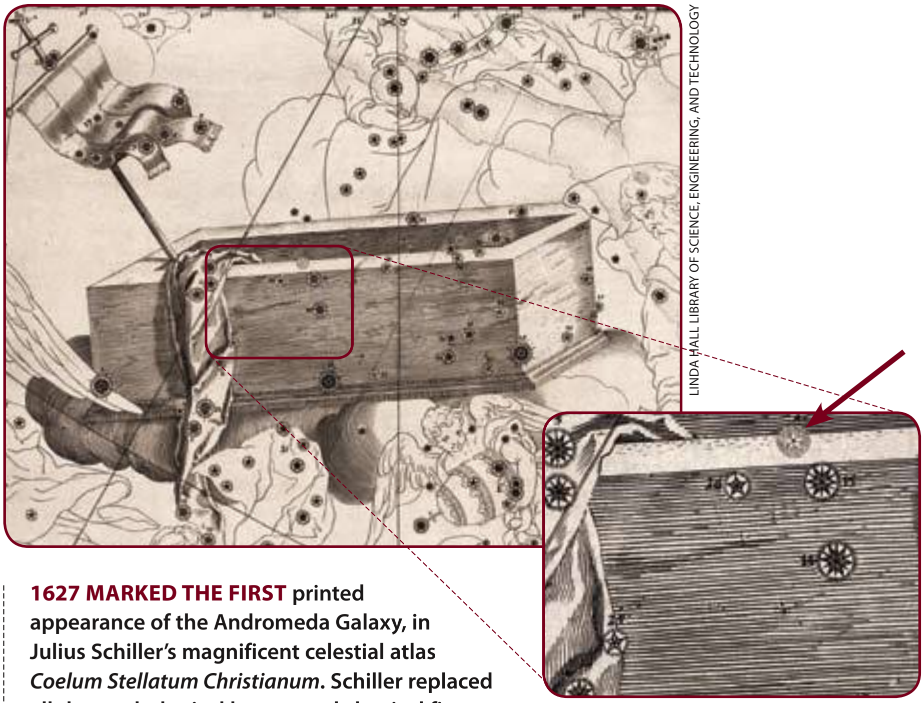
GALEX

THE GALAXY EVOLUTION EXPLORER (GALEX) is a satellite that records ultraviolet light emitted by celestial objects. In this image of M31, blue indicates star-forming regions, where young, hot stars trace out the galaxy's spiral arms. The warmer and whiter colors near M31's nucleus show where cooler stars formed long ago. The red stars in this image are foreground stars in the Milky Way. This image is a 10-part mosaic captured in September and October 2003.



NASA/SAO/CXC/M. GARCIA ET AL.

ANDROMEDA X RAYS. This image doesn't look like other Andromeda Galaxy images throughout this story because it's an X-ray close-up of M31's nucleus. Astronomers used the Chandra X-ray Observatory's Advanced CCD Imaging Spectrometer to probe the galaxy's central region and pin down the position of the supermassive black hole in its core. This 2.8-hour exposure, taken October 13, 1999, measures only 1' across — 0.5 percent of M31's apparent length.



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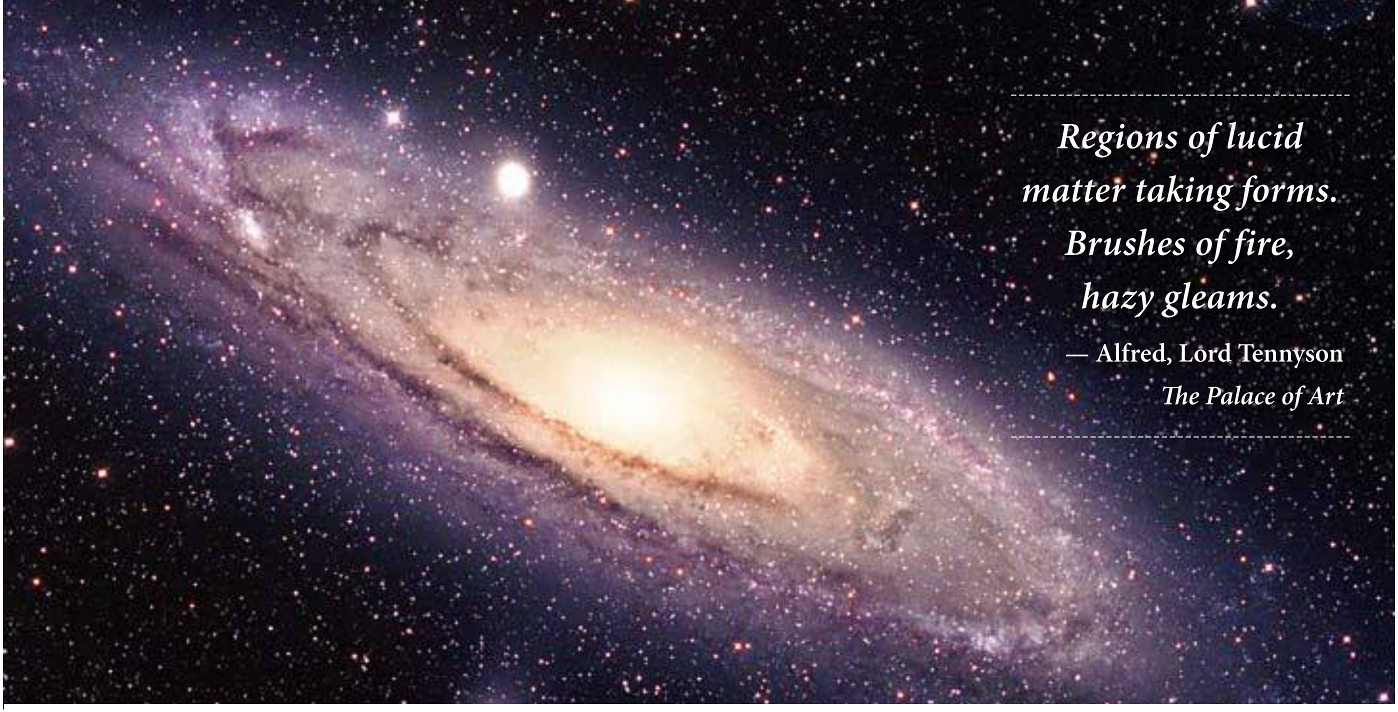
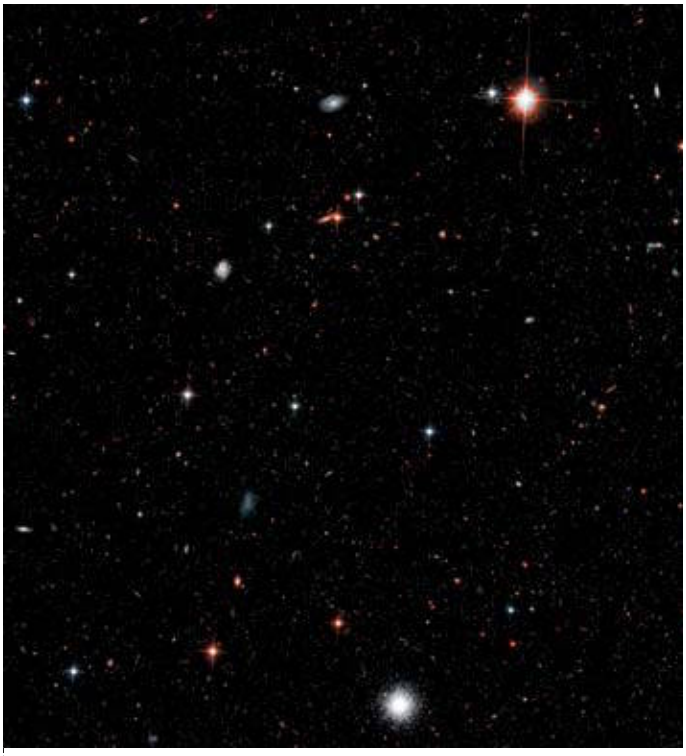
1627 MARKED THE FIRST printed appearance of the Andromeda Galaxy, in Julius Schiller's magnificent celestial atlas *Coelum Stellatum Christianum*. Schiller replaced all the mythological heroes and classical figures with constellations he invented from the Bible and Christian tradition. Andromeda became the Holy Sepulcher. The position of the "nebula," as the Andromeda Galaxy was known then, is on the front edge of the sepulcher, just to the left of center (arrow). It's labeled with the number 27 and makes a small triangle with stars labeled 26 and 15.



Regions of lucid
matter taking forms.
Brushes of fire,
hazy gleams.
— Alfred, Lord Tennyson
The Palace of Art

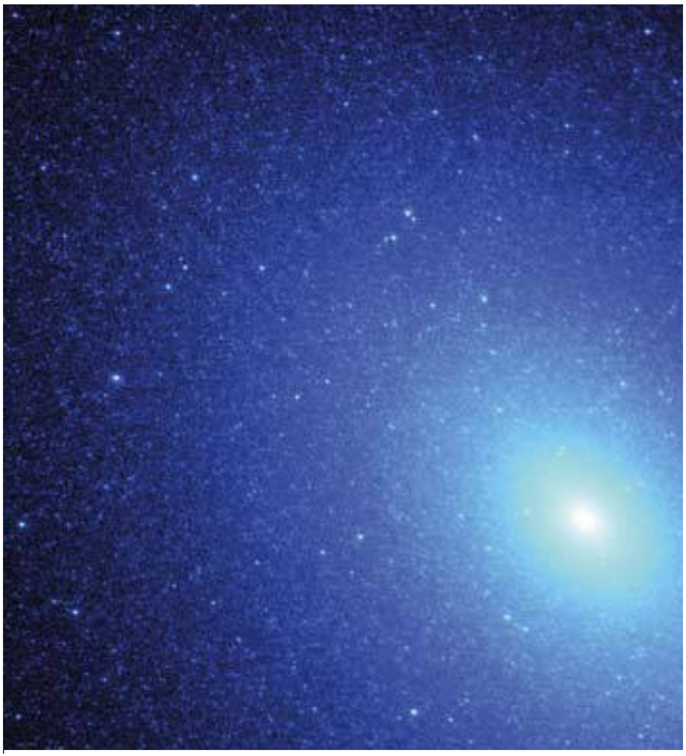
JASON WARE

PLANO, TEXAS, AMATEUR astronomer Jason Ware made this image of the Andromeda Galaxy with a 6-inch Meade 152 ED refractor at f/9. Ware took 75- and 90-minute exposures on 120mm Fuji HG400 film. From the negatives, he made two Kodak Vericolor transparencies. He recopied these to two internegatives, which he sandwiched to create prints. For this digital image, Ware scanned the original negatives and used image-processing software to enhance the detail.



NASA, ESA, AND T. M. BROWN (STScI)

THE ANDROMEDA DEEP FIELD is a four-image mosaic obtained with the Hubble Space Telescope's Advanced Camera for Surveys. It reveals 300,000 halo stars and up to 10,000 background galaxies. The image shows an area that lies 36,000 light-years from M31's nucleus. Between December 2, 2002, and January 11, 2003, Hubble made 250 separate exposures of this region. The resulting image has a total exposure time of 3.5 days and shows stars down to magnitude 31. The compact globular cluster GC 312 lies at the bottom. It contains 100,000 stars and is one of several hundred similar globulars that orbit M31.



THOMAS M. BROWN (GSFC) ET AL., NASA

ELLIPTICAL GALAXY M32 is a companion to the Andromeda Galaxy. Easily seen in small telescopes, this 8th-magnitude galaxy is 8,000 light-years in diameter. M32's mass is roughly 1/100 that of its neighbor. Measurements show M31 is overtaking M32 at a speed of approximately 1.4 million mph (2.2 million km/h). This Hubble shot of M32's center shows thousands of bright blue stars. Elliptical galaxies probably don't have young stars, so these blue stars must be old stars in the late stages of stellar evolution. Such objects glow blue for a short time when heavier elements begin to fuse in their cores.

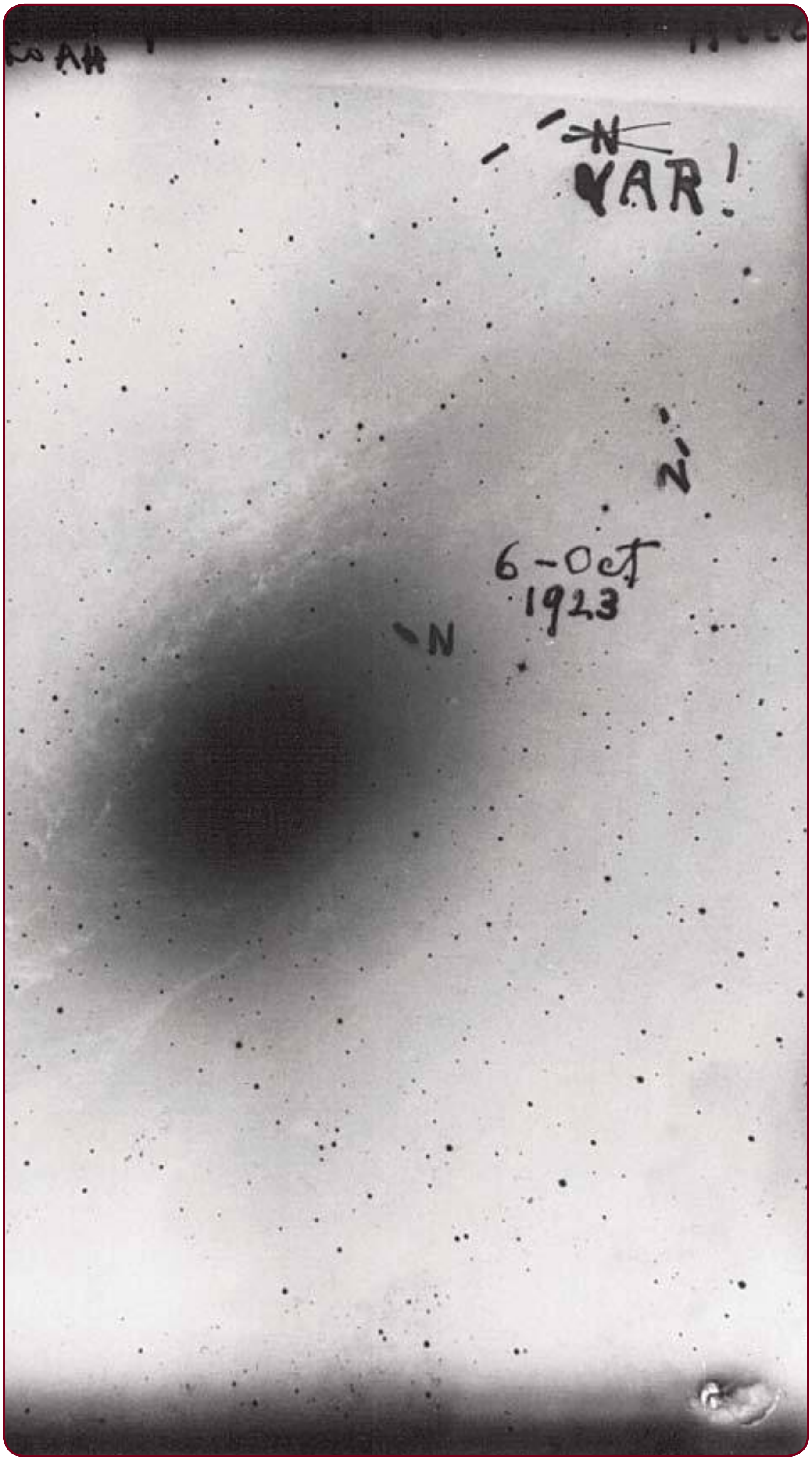
Early in the 20th century, Harvard astronomer Henrietta Swan Leavitt refined this measurement. Not far away in the northern sky, Andromeda's mythological father, Cepheus the King, contains a variable star designated Delta (δ) Cephei. The light from this star appears to brighten and fade with regularity. Leavitt found a relationship between the length of time of the variability — called the period — and the star's brightness, or luminosity. Because of this easy-to-calculate relationship, Cepheid variables quickly became the nearby universe's distance rulers.

In 1924, American astronomer Edwin Hubble turned the new 100-inch reflecting telescope atop Mt. Wilson in California toward M31. At the time, the 100-inch was the largest telescope in the world and the largest since Lord Rosse's Leviathan. It could resolve stars in the outer edge of the Andromeda Galaxy.

Hubble applied Leavitt's period-luminosity relationship to the identified Cepheid variable stars. He soon announced the Andromeda nebula was 750,000 light-years away, and that it was a galaxy of staggering proportions. This value remained unchanged for years, until astronomers realized Hubble had made comparisons among the wrong variables. Further study and revised values have pushed the Andromeda Galaxy to 2.5 million light-years away from Earth.

For all its vast distance, the Andromeda Galaxy is a close neighbor, astronomically speaking. In 1912, at Lowell Observatory in Flagstaff, Arizona, Vesto M. Slipher measured the "speed" of M31 and found it is moving fast. The Andromeda Galaxy is heading toward the Milky Way at nearly 670,000 mph (1,085,000 km/h). The distance between these giant spiral galaxies will keep them apart for about 2 billion years. Then, our galaxy will meet Andromeda head-on and merge with it to form a single monster galaxy.

Some people think the forward motion of science is made by men in white lab coats recording unfailing new data on clipboards. The story of M31 and how we know so much about it shows what a human endeavor scientific discoveries are. For more than 1,000 years, skygazers tried to piece together an accurate picture of what they saw in the sky. We are the privileged generation that has learned a few of the answers they sought.



CARNEGIE INSTITUTION OF WASHINGTON

NEBULA? NO. VARIABLE. Edwin Hubble's careful scrutiny of photographic plates of the Andromeda Galaxy led to an insight. Instead of being a nova, one star in M31 brightened and dimmed, revealing itself to be a Cepheid variable — a star whose period of variability is related to its brightness. Calculating its distance, Hubble found the Andromeda "nebula," as it was known at the time, could not possibly lie within our galaxy. After this epiphany, Hubble took his pen to the plate, crossed out the "N" (nova) and scribbled "VAR!" (variable).

ASTRONOMICAL HISTORY

Few astronomical topics are as confusing as star names. How did we get ourselves into this mess? /// BY MICHAEL COVINGTON

How stars got named

For thousands of years, people have been naming the stars. As a result, the names are a hodgepodge of Babylonian, Greek, Roman, Arabic, and Medieval Latin. Adding to the confusion, some stars have received several names over the millennia. Let's try to sort it all out.

/// UNUSUAL STAR NAMES

Name	Designation
Azelfafage	Pi^1 (π^1) Cygni
Baten Kaitos	**Zeta (ζ) Ceti**
Cih	Gamma (γ) Cassiopeiae
Dschubba	**Delta (δ) Scorpii**
Elmathalleth	Alpha (α) Trianguli
Fom	**Epsilon (ε) Pegasi**
Giedi Secunda	Alpha^2 Capricorni
Hoedus II	**Eta (η) Aurigae**
Izar	Epsilon Boötis
Jugum	**Gamma Lyrae**
Kaffaljidhmah	Gamma Ceti
Lucida Cymbae	**Alpha Phoenecis**
Minelauva	Beta (β) Virginis
Nunki	**Sigma (σ) Sagittarii**
Oculus Boreus	Epsilon Tauri
Peacock	**Alpha Pavonis**
Rutilicus	Beta Herculis
Sham	**Alpha Sagittae**
Tarf	Beta Cancri
Unukalhai	**Alpha Serpentis**
Vindemiatrix	Epsilon Virginis
Wasat	**Delta Geminorum**
Yed Posterior	Epsilon Ophiuchi
Zubenelgenubi	**Alpha Librae**

Take the star Sirius, for example. Its name comes to us from ancient Egypt. The brightest nighttime star, it is known by no fewer than 54 identifiers. Among the more well-known designations are Alpha (α) Canis Majoris, the Dog Star, 9 Canis Majoris, BD-16 1591, HD 48915, HIP 32349, LTT 2638, SAO 151881, and USNO 816. Sirius has more aliases than a con artist.

Uniformity — forget it

No official list of star names exists. The ancient Greeks, who borrowed nomenclature from earlier civilizations, assigned many of the names we recognize today.

The Greeks freely substituted and made up new names. These developments were more or less complete by 300 B.C., and Ptolemy's *Almagest*, written around A.D. 150, summed up the Greek picture of the sky. *Almagest* is a catalog of 1,025 stars arranged in 48 constellations. Of the 88 constellations known today (formalized by the International Astronomical Union in 1928), 49 are based on Ptolemy's work.

With regard to star names, the Romans borrowed heavily from their Greek predecessors. But once Rome fell in the fifth century, European scholarship in all areas — not just astronomy — foundered.

Regions of the Middle East and North Africa, once under Greek and then Roman rule, became part of the Ottoman Empire, which had a vital intellectual life during the European Dark Ages. The works of Greek scholars were translated into Arabic starting in the ninth century, and eventually, they filtered into Europe through Ottoman Spain in the 12th century. The Arabic was translated back into Latin and Greek, but European scholars tended to make hash of the Arabic they were translating.

Betelgeuse, for example, was apparently somebody's transcription of *bad al-jawza*, which is quasi-Arabic. It's a miscopying of *yad al-jawza* ("hand of al-jawza") or possibly *ibt al-jawza* ("armpit of al-jawza"). *Al-jawza* could mean "the giant," "the central one," or even "the white-bellied sheep."

Betelgeuse could also be *bait al-qaws* ("archer's quiver"). And the corruption doesn't stop there. Because of a misprint in 1720, Betelgeuse is still called Beteigeuze on some German maps.

Other Arabic names survived nearly intact — for example, "Deneb," which means "tail." This word forms part of at least 12 star names, including Deneb Algedi (Delta [δ] Capricorni), Deneb Kaitos (Beta [β] Ceti), and Deneb Okab (Delta Aquilae). When Deneb is used alone, it refers to Beta Cygni. Many star names also contain the Arabic prefix *al-* ("the"), such as Aldebaran ("the follower") and Algol ("the ghoul").

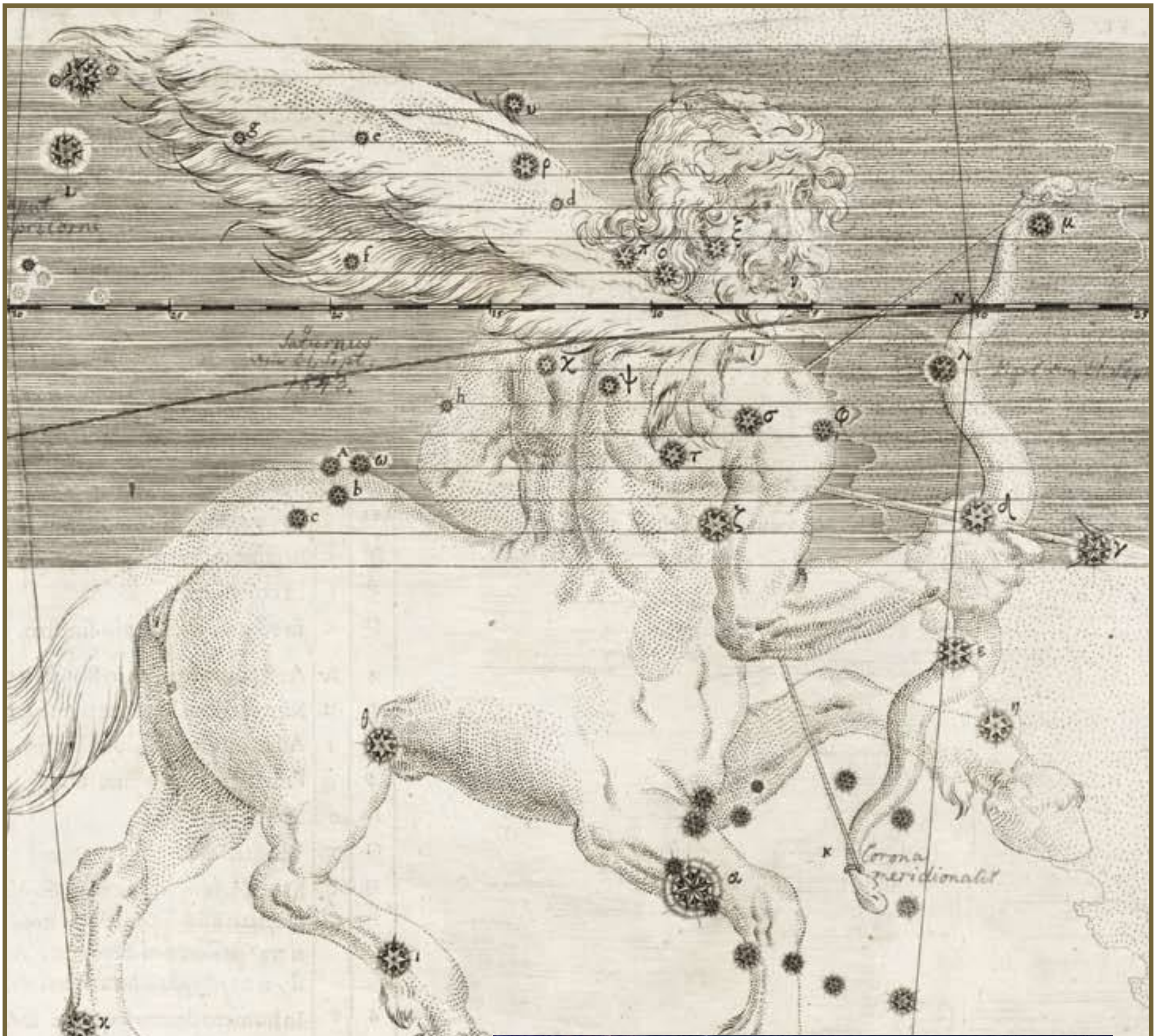
In some cases, a name's origin is truly obscure. Albireo, for instance, is reportedly a mistranslation of *ab ireo* ("from ireo") in a 1515 printed edition of Ptolemy's *Almagest*. That would be a fine translation if only we knew what "ireo" meant.

Early schemes

Many stars never had names, so early modern astronomers gave them letter and number designations. The two systems most widely used are the Greek letters assigned by German lawyer Johannes Bayer (1564–1617), and the numbers associated with the stars in the catalog of British astronomer John Flamsteed (1646–1719).

Bayer's star atlas, *Uranometria*, appeared in 1603. He designated the stars of each constellation in order of decreasing brightness: Alpha is the brightest star, Beta is second brightest, and so on. But there are numerous examples in which the designations are out of order.

Bayer's system was extended to the southern sky by Nicolas-Louis de Lacaille



Corona meridionalis

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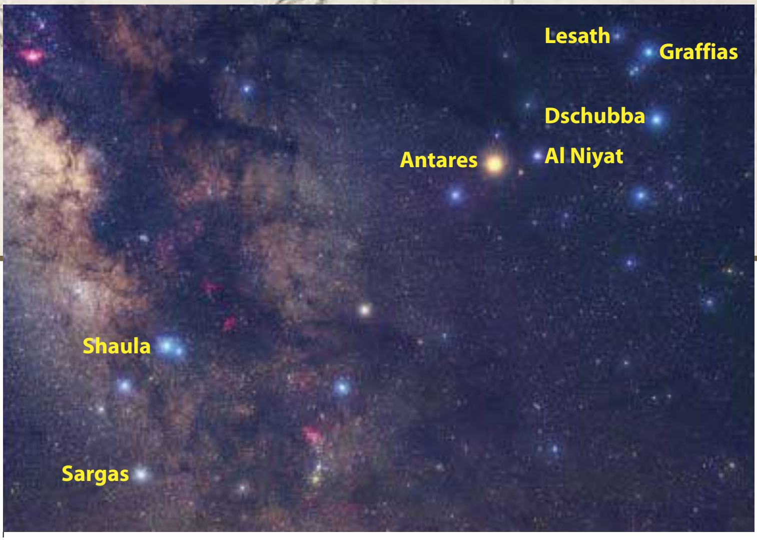
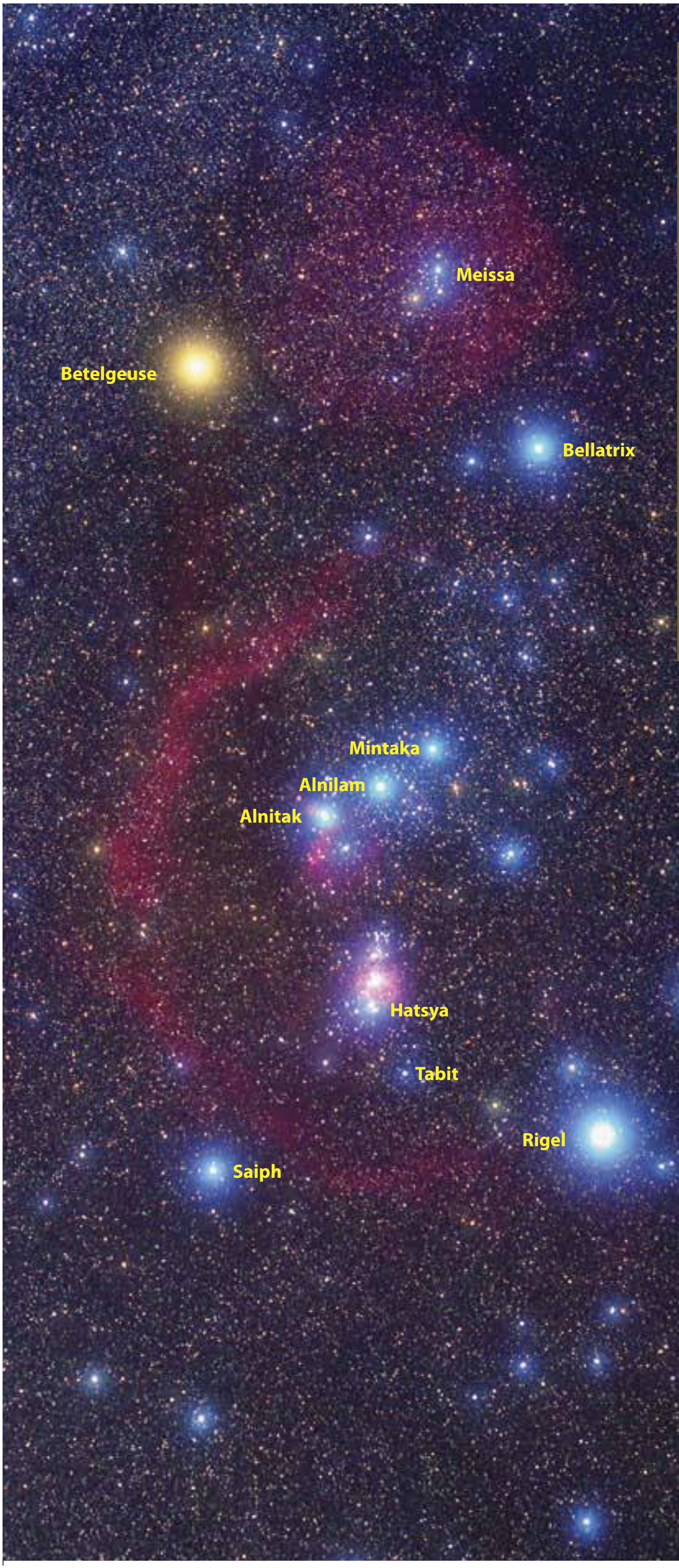
SAGITTARIUS THE ARCHER contains some unusual star names. Among them are Al Nasl (γ), Arkeb Pesterior (β²), Kaus Meridionalis (δ), Nunki (σ), and Rukbat (α). This illustration is from *Uranometria* by Johannes Bayer. Published in 1603, it was the first star atlas to identify the stars using Greek letters.



Lesath
Graffias
Dschubba
Antares
Al Niyat
Shaula
Sargas

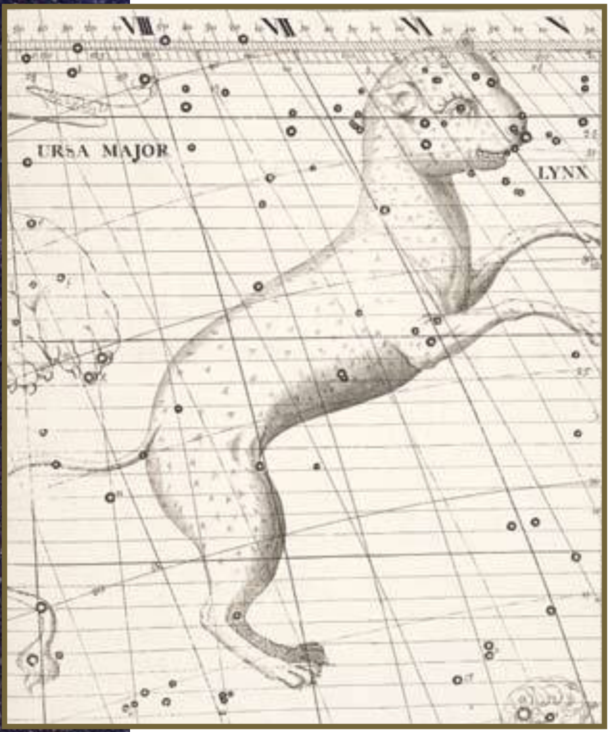
BILL AND SALLY FLETCHER

SCORPIUS THE SCORPION lies near the southern horizon, against the backdrop of the Milky Way, for most northern observers. The scorpion's best-known star is Antares ("rival of Mars").



ORION THE HUNTER has many bright stars that have been given unusual names.

BILL AND SALLY FLETCHER



LYNX is a faint northern constellation near Ursa Major the Great Bear. This illustration is from the first edition of John Flamsteed's *Atlas Coelestis*, published in 1729. Numbers now named for Flamsteed that identify the bright stars in constellations appeared in a later, French edition of this work, which was edited by Joseph Jerome de Lalande.

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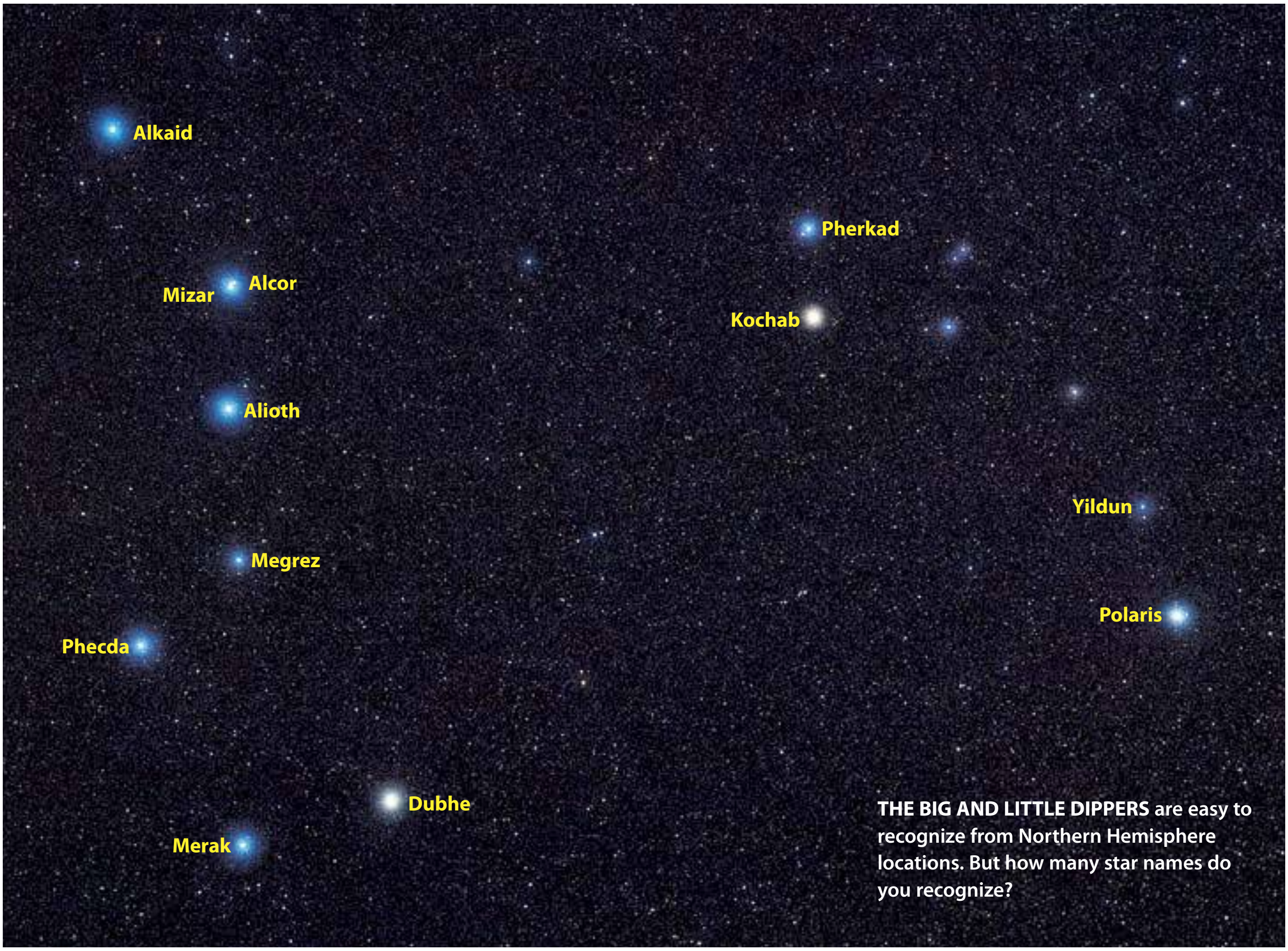
(1713–1762), who mapped nearly 10,000 stars and named 14 new constellations on a trip to the Cape of Good Hope in the 1750s. After the 24 Greek letters, Bayer and Lacaille extended the system by using first lowercase Latin letters (a–w), and then uppercase (A–Q), but most of these are no longer used.

Meanwhile, Flamsteed, working in England, designed a star atlas that was published posthumously in 1729. Flamsteed's maps, by the way, contain only Greek letters — no so-called Flamsteed numbers. The numbers actually originated in a French edition of the atlas and its accompanying catalog. The editor, Joseph Jerome de Lalande (1732–1807), assigned numbers to the stars in the catalog. So, it was not Flamsteed

Michael Covington *is the author of* Celestial Objects for Modern Telescopes *(Cambridge University Press, 2002). He learned Latin, Greek, and the stars and constellations at an early age and has never been the same.*



THE BIG AND LITTLE DIPPERS are easy to recognize from Northern Hemisphere locations. But how many star names do you recognize?

BILL AND SALLY FLETCHER

who introduced the Flamsteed numbers, but Lalande. He numbered the stars in order of increasing right ascension, giving the desleiptions such as 1 Andromedae, 2 Andromedae, and so forth.

In most of the sky, Flamsteed numbers have replaced all but the first dozen or so Bayer letters. However, Flamsteed's atlas did. not extend to the far southern sky, so Bayer letters are still used there. Read more about the star atlases of Bayer, Flamsteed, and others in "Mapping the classical sky" in the December 2004 issue of *Astronomy*.

Go look it up

Bayer and Flamsteed designations cover only stars brighter than 7th magnitude. For fainter stars, astronomers use the numbering from any of several star catalogs: the Henry Draper Catalogue (HD), the Smithsonian Astrophysical Observatory Star Catalog (SAO), and sometimes, the Yale Bright Star Catalogue (YBS, or HR). Most computerized telescopes can look up stars by their SAO numbers.

The most authoritative star catalog in use today is Hipparcos (HIP), based on the measurements made by the European Space Agency (ESA) satellite of the same name. Hipparcos star numbers probably will displace most older catalog designations in future scientific work.

The HIP catalog is accurate, giving star positions to a fraction of an arcsecond. Alongside HIP, the ESA also published the Tycho Catalog (TYC), based on less exact measurements made with another instrument on the same satellite. TYC contains a lot more stars. It reaches about magnitude 11 and is the first good catalog to do so. The final Hipparcos Catalog (120,000 stars to visual magnitude 7.5 measured to 1 milli-arcsecond accuracy) and the final Tycho Catalog (more than a million stars to photographic magnitude 10.5 measured to 20–30 milli-arcsecond accuracy) were completed in August 1996.

One catalog that probably will not endure is the Hubble Guide Star Catalog (GSC), which was put together quickly by digitizing photographic plates to generate a list of guide stars for the Hubble Space Telescope. Although many popular software packages include GSC data, the catalog is incomplete — a patch in Hercules is missing altogether — and the magnitude limit varies in different parts of the sky.

Using star names today

How, then, should a 21st-century amateur astronomer deal with star names? Should you memorize all 3,000 of them? Hardly. It's really a judgment call. Astronomy educators probably need to know more star names than professional astronomers. Some amateur istronomers pride themselves on the number ofritars they can identify by name and the number of legends they can recite about them. As long as these dedicated individuals are still around, the storied history associated with star names will never be lost. **A**

ONLINE EXTRA Find out how objects are named today at www.astronomy.com/toc

AMATEUR ASTRONOMY

Observe the stars and preserve your yard's aesthetics with this clever design.

/// TEXT AND IMAGES BY **KENNETH D. WHEAT**

Invisible observatory

If you don't have the time or money to build a permanent observatory, do what I did: Build an observation deck in your backyard. This platform is a simple alternative that offers a soft bounce for your legs, provides the stability of a pier mount, and keeps your tripod intact.

An idea is born

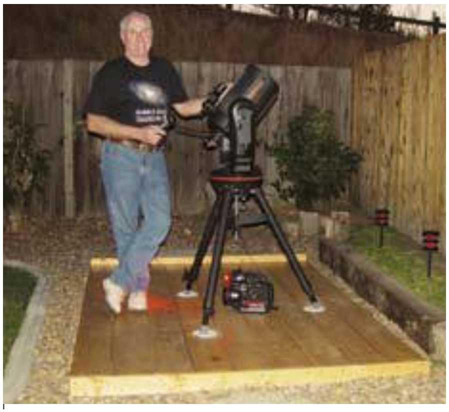
I always had an interest in astronomy, but it took my brother-in-law to get me to jump into it with both feet. He helped me select my first telescope — a 5-inch Maksutov — and, after viewing Saturn, I was hooked. On his advice, I eventually bought an 8-inch Schmidt-Cassegrain telescope. It's a large enough scope to capture many of the "faint fuzzies" I'd want to observe while using portable equipment.

Because of my yard's landscaping, the best sky view for my new telescope was in an area decorated with river rock. I used this spot for a while, but my legs, feet, and knees took a beating. This arrangement had to be changed!

I wanted something easy on my body at night, and easy on my eyes during the day. I kept thinking about a deck, but I knew a telescope on such a surface was not a good idea — every movement would cause vibration, interfering with the astrophotography I was eager to try.

Construction

My solution was a simple deck with three small piers. I used treated 10' and 8' four-by-fours for the frame's foundation. The frame was set down, leveled, and squared. Two 8' four-by-fours down the middle of the frame added inside support. In addition, I connected all pieces with 4" L-brackets. To stabilize the frame, I drove a dozen 12" wooden stakes into the ground and secured them with 3" drywall screws, two to each four-by-four.



THE DECK IS PRECISELY SIZED for the author and his 8-inch Celestron Schmidt-Cassegrain telescope.

I placed my telescope in the middle of the newly constructed deck foundation, turned on my Global Positioning System (GPS) unit, and polar-aligned my scope. I marked the location of each tripod leg with a stake. Then I moved the tripod legs another 2" to get the rear leg in the position I wanted. I again used my GPS to make sure both the back leg and the scope were pointed north. I noted with stakes the new tripod-leg positions.

For my piers, I bought a 4½" diameter, 8' long, heavy-duty ABS plastic pipe. Using my table saw, I cut three 30" tubes.

/// MATERIALS LIST

Item	Quantity
Lumber (treated) — 10' four-by-four	2
Lumber (treated) — 8' four-by-four	4
Lumber (clear fir) — 10' two-by-ten	9
Lumber (clear fir) — 8' one-by-four	2
ABS plastic pipe — 8' by 4½", ¼" thick, black	1
60-pound bag of cement	3 bags
Drywall screws — 3"	30
Drywall screws — 4"	100
L-brackets — 4"	8
Waterproof stain	1 gallon
Wooden stakes — 12"	12
Bright white enamel spray paint	1 can

All materials were purchased at a local hardware store. The total cost was $140. The project took 2 days to complete.

Using a post-hole digger, I dug my first pier hole a little more than 30" deep. I inserted a 30" pipe and packed a small amount of cement around the outside to keep the pipe in place.

I measured the center point of the pipe to my second stake to make sure the distance was still correct from pier to pier. I placed two 10' two-by-ten deck boards on each side of the first pier. I used these boards as guides so the pipe would be level with the top of the deck boards.

I packed cement around the pipe and repeated the same steps for the other two

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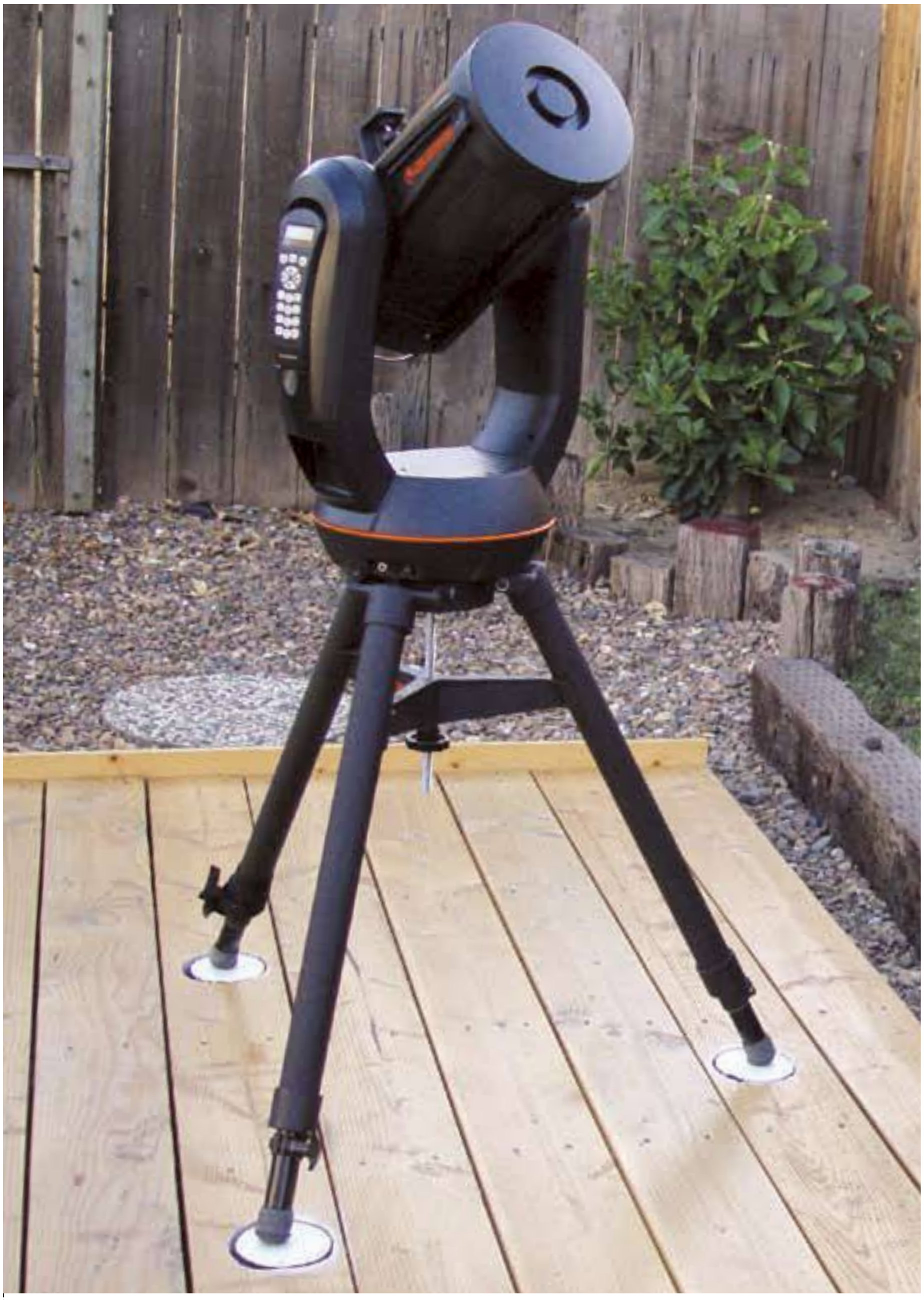
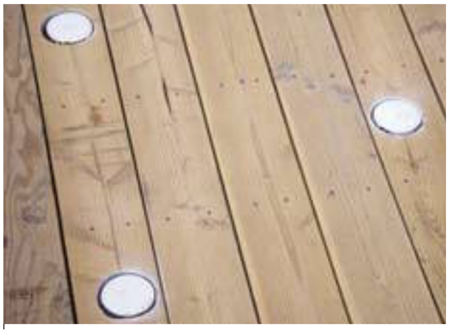
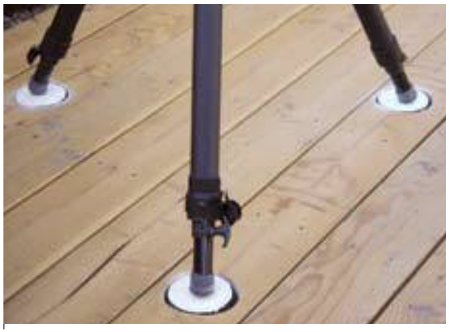
Kenneth D. Wheat *has been an amateur astronomer and photographer for the past 5 years. He enjoys quality time with his family.*



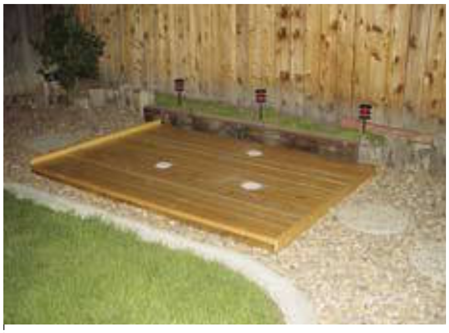
THE OBSERVING DECK was constructed with only one telescope in mind — the author's 8-inch Schmidt-Cassegrain.



THE THREE PIERS of the observing deck are columns of cement 4½" in diameter and 30" deep.



THE TRIPOD LEGS of the author's 8-inch Schmidt-Cassegrain telescope fit exactly on top of the three piers.



THREE LIGHTS and a raised rear rail provide nighttime safety.

piers. I filled each ABS pipe all the way to the top with cement, leveling the material with a trowel. In all, I used 180 pounds of cement for the three piers.

The next day I laid down the floor — 10' two-by-ten top deck boards. I used 4" drywall screws to secure the boards to the frame. This way, if any board gets damaged, I can just unscrew and replace it.

Starting on one side, I secured each board successively to the frame until I reached my first pier. I skipped that board (using it only as a spacer) and went to the next, repeating the process until all the boards were fastened except the two that were to go over the piers.

I painted the top of each pier with white enamel, and, before the paint had a chance to dry, placed the corresponding deck board over the wet surface. Five seconds later, I removed the boards and a 4½" white ring remained on the wood, showing where I needed to cut my holes.

With a compass, I made three 5" circles, which I cut out with a saber saw. I placed the boards back over the piers for a perfect fit. Each hole left ¼" around the pier. This prevents vibrations from shaking the piers and tripod legs that sit on them. I installed two 8' one-by-four boards on each end of the deck. I made the back-end board 2" higher so my observing chair won't slip off the edge in the dark.

Each pier then received another coat of white enamel, and the deck received three coats of waterproof stain. I placed three lights on one side of the deck. The glass lenses were removed, painted red, and replaced. The soft glow provides me with just enough light for visitors' safety and for me to see what I'm doing while preserving my night vision.

The finished deck is all I'd hoped for. By night, it allows me to set up my telescope quickly and observe in comfort. By day, it's an almost unnoticed addition to my yard. ◼

A permanent observing site lets this astroimager pursue celestial quarry quickly and easily. /// IMAGES AND TEXT BY **GEORGE GREANEY**

Anchored to the stars

Until the fall of 2002, I typically would drive at least 3 hours to a remote site in the mountains, then set up for an imaging run. Needless to say, lugging around hundreds of pounds of equipment wasn't the best way to unwind after a long, sometimes treacherous, trip.

SHARON GREANEY

DOCTOR BY DAY and astroimager by night, George Greaney looks forward to the next generation of technology — especially if it means getting to the imaging even quicker.

Linking a computer, charge-coupled device (CCD) camera, and the equipment's power source added to the already laborious and lengthy process. So, after almost 14 years and countless skinned knees, I caved to the persuasive power of my aching back and started looking for a permanent observing site.

I live in Las Vegas, so a backyard observatory was not an option. As luck would have it, a ranch owner in the rural community of Ash Meadows, Nevada, invited me to his property to scout possible locations for a private observing station.

Located just 90 minutes from Las Vegas, his property had an ideal site with plenty of space to construct a small building to store equipment and an adjacent concrete pad for the preassembled setup (see below). The site is now home to Ash Meadows Observatory, a climate-controlled building with AC power and comfortable, if somewhat cramped, living quarters.

Equipment

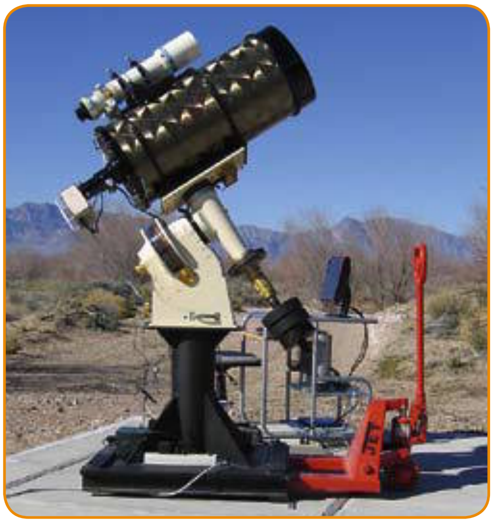
My telescopes and mount rest on a pier that is welded to a sturdy aluminum pallet. Using a pallet jack, the entire setup moves easily from the building to the nearby imaging station. Permanent markers align the pallet and pier to the North Celestial Pole.

A sturdy, high-quality mount is as important as the telescope and camera. Because of this, I use a Byers Series II German equatorial mount with an 11.45-inch R.A. — right ascension — gear. Quick tip: The bigger the drive gear, the more accurate the drive. For example, when imaging galaxies at long focal length, I use an Optical Guidance Systems 14.5-inch, f/7.9 Ritchey-Chrétien telescope with a carbon fiber optical-tube assembly and zero-expansion optics. The materials ensure changing temperatures — which, in a short amount of time, can be drastic in the desert — will not affect the optics.

The secondary mirror assembly is equipped with a digital focuser from

In the arid Southwest, an unoccupied observatory must endure blowing dust and the invasion of undesirable crawling pests. I chose not to construct a traditional roll-off roof observatory because I visit the site only a few days each month.

A PALLET JACK



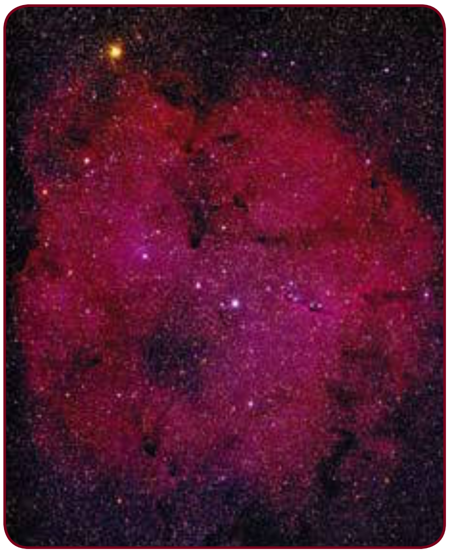
/// ASTROIMAGING ARTICLES FROM *ASTRONOMY*

In "Shoot sharper with film" (April 2005), Jason Ware explains how he captures stunning astrophotos on film.

For tips on how to capture great images with just a telescope and a webcam, read Damian Peach's "Small eyes on the sky" (May 2005).

Ruben Kier's "Build an astro-shed" (November 2004) explains how you can maximize the capabilities of your equipment while minimizing its impact on your land.

Also, read Kenneth D. Wheat's "Invisible observatory" on page 94.



IC 1396 **(Astro-Physics 6-inch f/7 refractor on a Byers Series II mount, Pentax 6x7 medium-format camera, hypered 120mm Fuji SHG400 film, digital composite of two 60-minute exposures; taken August 21, 1993, from Oak Springs summit near Caliente, Nevada)**

Technical Innovations called *Robofocus*. When run with *FocusMax* — shareware available at www.focusmax.org designed to focus a telescope automatically — this sophisticated automated focusing tool uses a stepping motor controlled by a microprocessor to provide digital feedback of the focus point. Put simply, the two programs work together to produce tack-sharp, high-quality images.

Quick tip:

The bigger the drive gear, the more accurate the drive.

I use a Takahashi FSQ-106 f/5 refractor — fitted with a *Robofocus* unit — for wide-field CCD imaging. Santa Barbara Instrument Group's (SBIG) large-format self-guiding CCD camera, the STL11000M, is attached to the telescope and can image extended objects. The Takahashi refractor allows me to image the same area of sky that I used to capture years ago with my 6-inch refractor.

An Astronomik Type 2C 48mm LRGB filter set with matched ultraviolet and infrared-blocking filters presents the target object in its true color. The filters thread into the camera's internal color filter wheel.

Through a process called white balancing, the camera sensor averages the light within the scene and adjusts internal color balance automatically to zero-out any generalized color bias. After white balancing, my RGB filter weights — exposure times for red, green, and blue to acquire equal energy through each with respect to the CCD chip — are 0.87:1.00:0.91.

A computer on a small desk runs *CCDSoft*. This image-processing and CCD-camera control software — a product of both SBIG and Software Bisque — integrates with *TheSky Professional Edition* for hands-on or automated telescope operation for observatory control.

A night of imaging

Usually, I arrive at the observatory by sunset and roll the setup out to the concrete

/// HIS SETUP, HIS EQUIPMENT

Technical Innovations
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[w] www.homedome.com

Finger Lakes Instrumentation, LLC
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Lima, NY 14485
[t] 585.624.3760
[w] www.fli-cam.com

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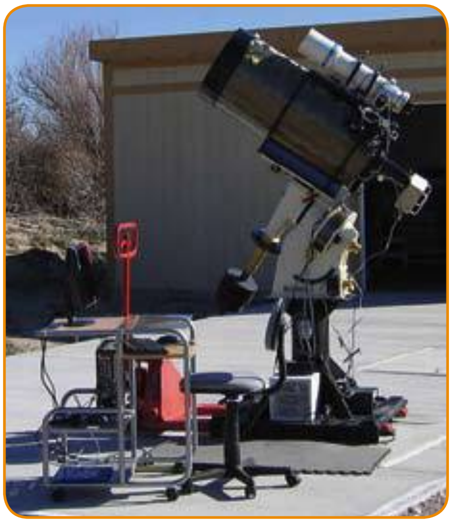


pad. I use the drift-scanning method (see "Drift scanning 101," page 100) to check the scope's polar alignment, which rarely requires adjustment.

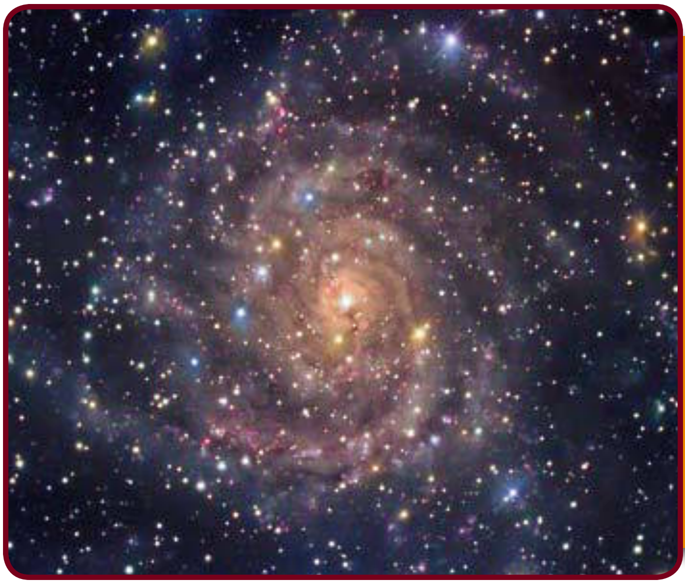
The camera connects to the telescope close to the correct focus position, then links to the computer. Before the imaging session can commence, the camera must reach its operating temperature of –4° Fahrenheit (–20° Celsius).

As the camera cools, I head back into the building to plot the night's target objects. With its database containing information on more than 200,000 objects, E. L. B. Software's *Megastar* — similar to *TheSky* — provides a detailed map of a target region. A CCD overlay centers the object, and the mount's autoguider chip locks to a suitable guide star — which keeps the target centered as Earth rotates.

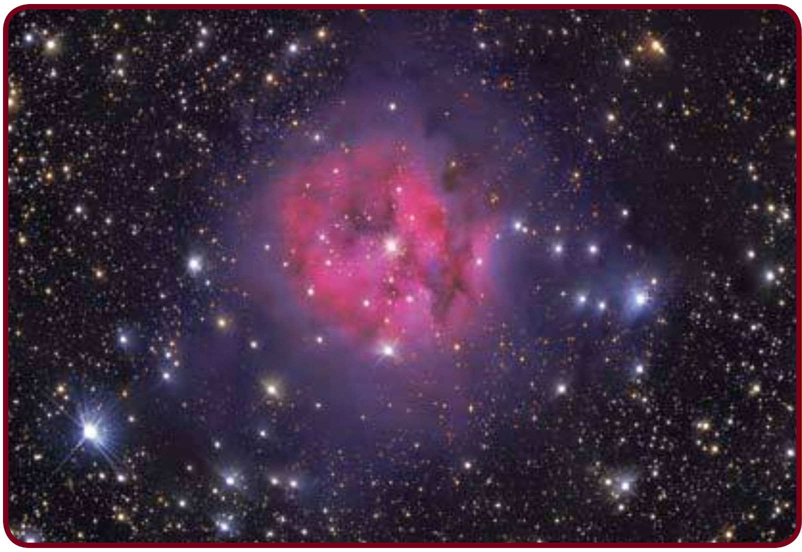
After acquiring my target through the telescope and centering it in the frame, I rotate the camera until the target and guide star match the map created earlier. Then I tighten the wire connections and run *FocusMax* and *Robofocus* to fine-focus the telescope using a star in the image frame.

By now, the camera has cooled, and I'm almost ready to image my target object. With a few more tweaks to the camera settings before imaging, it's critical the sky remains clear and cooperative.

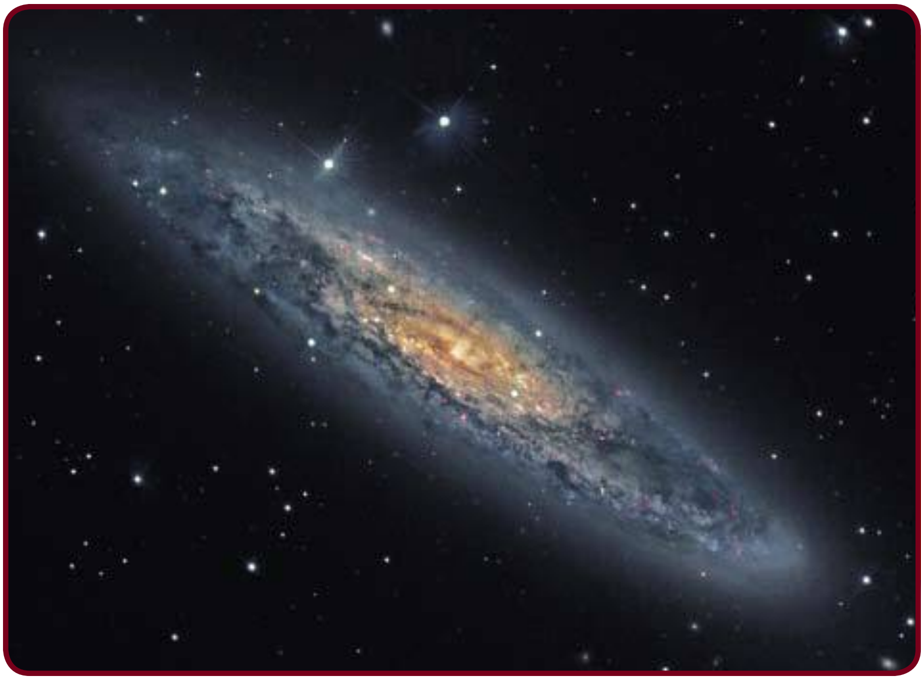
The CCD chip is binned 1 by 1 for luminance exposures (the L of LRGB) — usually unfiltered exposures to collect the most light — and 2 by 2 for RGB exposures. Essentially, 1 by 1 represents the



IC 1342 (Optical Guidance Systems 14.5-inch Ritchey-Chrétien telescope at f/6 on a Byers Series II mount, SBIG ST10E CCD camera [luminance data], FLI IMG1024 [color data], LRGB image with exposures of 180, 50, 75, and 75 minutes, respectively; taken January 22, 2004, from Ash Meadows Observatory, Nevada)



IC 5146 (Optical Guidance Systems 14.5-inch Ritchey-Chrétien telescope at f/7.9 on a Byers Series II mount, SBIG STL11000M CCD camera, LRGB image with exposures of 120, 50, 50, and 50 minutes, respectively; taken September 12, 2004, from Ash Meadows Observatory, Nevada)



NGC 253 (Optical Guidance Systems 14.5-inch Ritchey-Chrétien telescope at f/7.9 on a Byers Series II mount, SBIG STL11000M CCD camera, LRGB image with exposures of 120, 30, 30, and 30 minutes, respectively; taken August 22, 2004, from Ash Meadows Observatory, Nevada)

resolution the CCD chip delivers; 2 by 2 combines 4 pixels to act as one. Thus, the larger surface area can collect more light from faint objects — this extra light results in a more-detailed image.

Exposure times for raw images range from 10 to 15 minutes. Enough exposures consecutively taken give total integration times of 150 to 180 minutes for the L image and 30 to 50 minutes for each R, G, or B image.

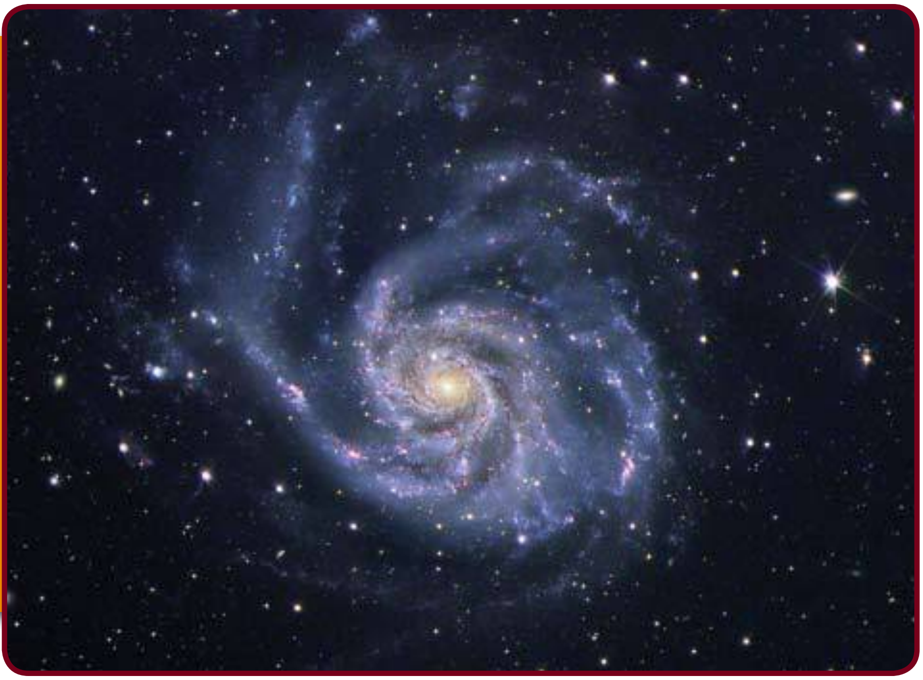
Before shooting my next object, I take my flat fields. Images of an object with even illumination — the twilight sky or the inside of an observatory — reveal problems such as dust, vignetting in the optical system, or differences in pixel sensitivity.

Imaging software takes the information from the flat fields and averages the sensitivity of all the pixels on the CCD chip — a uniform value for all the pixels leads to a better image. If all goes well, I can obtain the L images for two or three objects on the first night. As dawn nears, I cover my equipment and turn in for the day.

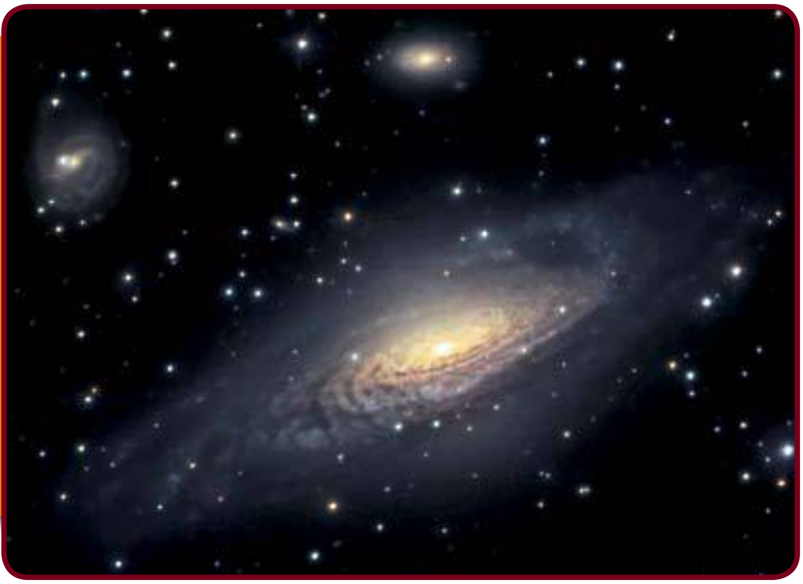
My wife Sharon and our dog Rigel often join me at Ash Meadows. On many occasions, I enjoy the company of fellow amateur astronomers as well.

During the day, we relax and read, drive to a local restaurant, or visit with the ranch owner. On the second evening, I shoot the RGB images.

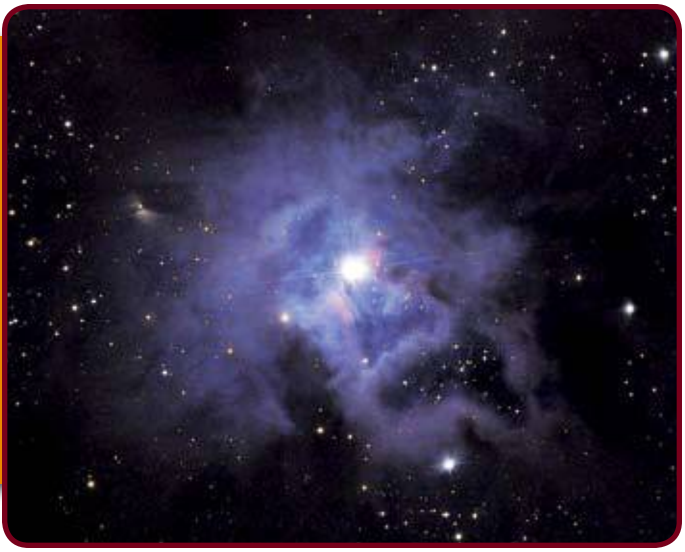
At the end of the second night's imaging run, all the photos are downloaded to a portable hard drive, the setup moved back into the station, and we settle in for a few hours of sleep before heading home.



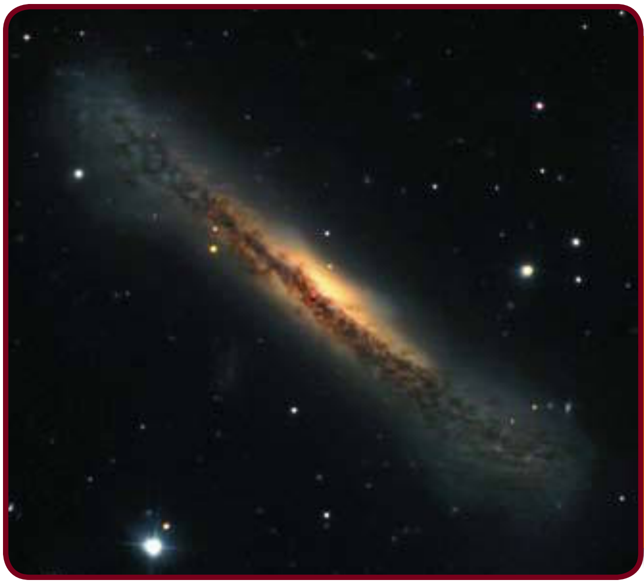
M101 (Optical Guidance Systems 14.5-inch Ritchey-Chrétien telescope at f/7.9 on a Software Bisque Paramount ME, SBIG STL11000M CCD camera, LRGB image with exposures of 180, 50, 50, and 50 minutes, respectively; taken April 11, 2005, from Ash Meadows Observatory, Nevada)



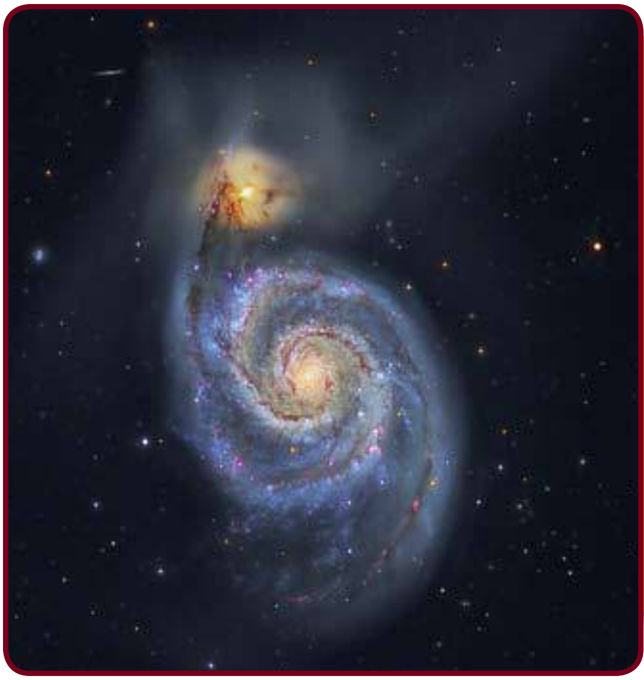
NGC 7331 (Optical Guidance Systems 14.5-inch Ritchey-Chrétien telescope at f/7.9 on a Byers Series II mount, SBIG ST10E CCD camera [luminance data] and FLI IMG1024 [color data], LRGB image with exposures of 150, 25, 40, and 40 minutes, respectively; taken September 25, 2003, from Ash Meadows Observatory, Nevada)



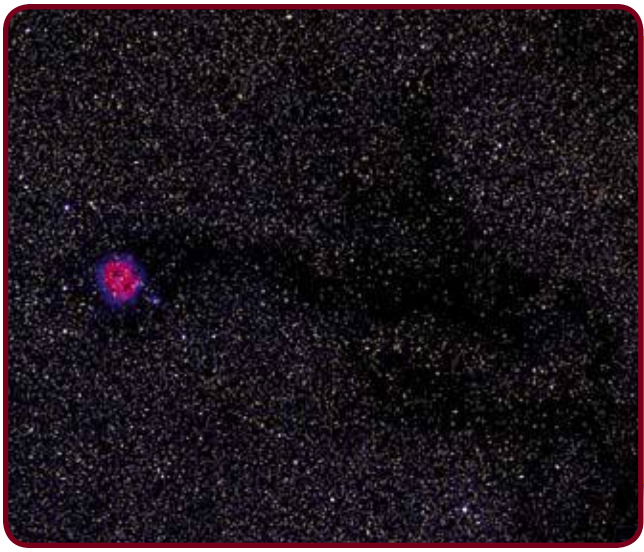
NGC 7023 (Optical Guidance Systems 14.5-inch Ritchey-Chrétien telescope at f/7.9 on a Byers Series II mount, SBIG STL11000M CCD camera, LRGB image with exposures of 110, 30, 30, and 30 minutes, respectively; taken June 19, 2004, from Ash Meadows Observatory, Nevada)



NGC 3628 (Optical Guidance Systems 14.5-inch Ritchey-Chrétien telescope at f/7.9 on a Byers Series II mount, SBIG ST10E CCD camera [luminance data] and FLI IMG1024 [color data], LRGB image with exposures of 110, 25, 37.5, and 37.5 minutes, respectively; taken January 4, 2003, from Ash Meadows Observatory, Nevada)



THE WHIRLPOOL GALAXY (M51) (Optical Guidance Systems 14.5-inch Ritchey-Chrétien telescope at f/7.9 on a Software Bisque Paramount ME, SBIG STL-11000M CCD camera, LRGB image with exposures of 210, 80, 80, and 80 minutes, respectively; taken April 5–6, 2005, from Ash Meadows Observatory, Nevada)



THE COCOON NEBULA (IC 5146) (Astro-Physics 6-inch f/7 refractor on a Byers Series II mount, Pentax 6x7 medium format camera, hypered 120mm Fuji SHG400 film, digital composite of two 60-minute exposures; taken August 21, 1993, from Oak Springs summit near Caliente, Nevada)

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/// DRIFT SCANNING 101

Sometimes referred to as time-delay-and-integration (TDI) mode, drift scanning utilizes a telescope/CCD setup without a drive that is pointed at a particular spot in the sky. Attempting to image a celestial object this way would result in a hopeless blurring of the image. But drift scanning depends on the apparent motion of the stars.

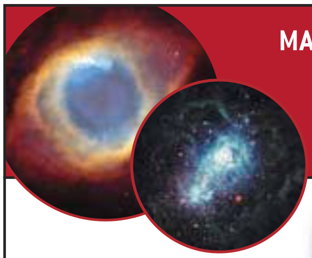
The CCD chips of setups in drift-scan mode are aligned so Earth's rotation causes objects to move exactly along the columns of pixels comprising the chips. Using imaging software with options for drift scanning, pixels within columns on the chips read out at the same rate at which the objects appear to be moving, called the sidereal rate. Thus, the light from a star (or asteroid) falls on different pixels within the column but is added together to form a single image. The result is a long, thin image in which point sources appear as points, not streaks. Many new asteroids have been discovered by this method.

The advantage to drift scanning is in the cost of the setup and the types of telescopes that may be used. With drift scanning, only the optical tube is required — no mount! Some amateur astronomers who use drift-scanning methods literally have bolted their telescopes to steel beams. And, for the first time, large Dobsonian-mounted telescopes may be used for asteroid work because the mount plays no part at all in acquiring the image.

Be certain to check with your CCD camera manufacturer to ensure the camera's software includes the option of drift scanning.

— Michael E. Bakich

George Greaney *is an anesthesiologist in Las Vegas who hosts his own astroimaging web site from his home.*



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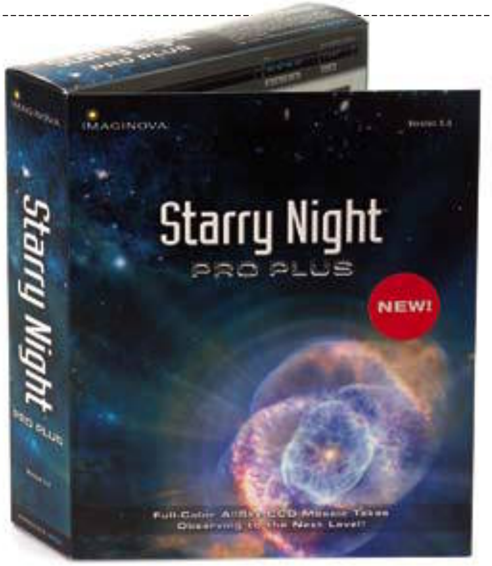
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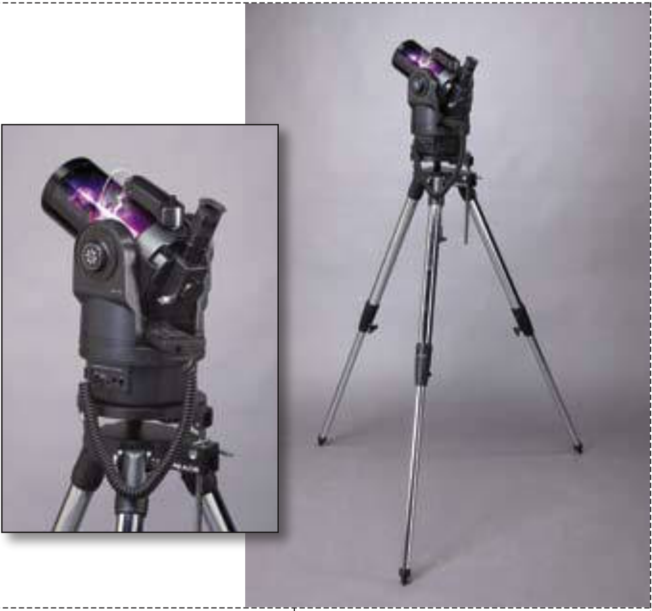

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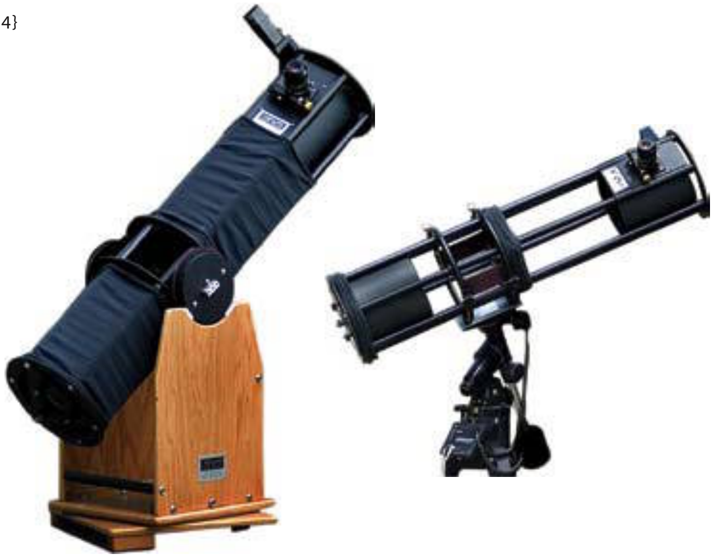

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The latest update to the *Starry Night* astronomy software line adds an AllSky CCD mosaic and a full-color photograph of the entire night sky visible from Earth to the features, data, and images of the previous Pro version. The new edition also provides more telescope-control options and is released on DVD-ROM format only.

$249.95; Imaginova
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[t] 800.252.5417
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The first model of Starmaster Portable Telescopes' new Versa Series is the V8, an 8-inch scope with an f/5.6 mirror. The entire telescope — around 35 pounds — disassembles in less than 5 minutes with a Phillips screwdriver. Standard features include a zero-power finder scope, a secondary dew heater, and an adjustable focusing plate.

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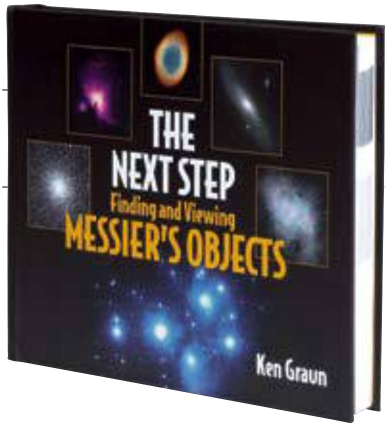


Now try a Messier marathon

The Next Step: Finding and Viewing Messier's Objects

Ken Graun, 352 pages, Ken Press, 2005; hardcover, $29.95

Over the past 30 years, a number of books have focused on helping novices find and observe the Messier catalog of deep-sky objects. But of all the books I have read, none is better suited for the beginner than Graun's book. Its 352 pages cover a range of topics from an historical overview, basics on telescopes and observing, star charts, and, of course, the entire Messier catalog.

Graun opens with more than 50 pages on not only the life of Charles Messier, but also detailed accounts on his colleague Pierre Mechain and associates Joseph Nicolas Delisle and Joseph Lalonde; and even a section on John Louis Emil Dreyer, the compiler of the NGC and IC catalogs. Profusely illustrated and well-researched, this section gives the reader a sense of what it was like living and observing in the late 17th and early 18th centuries. There is also a fanciful discussion between the author and Messier over his omission of the Double Cluster from his catalog.

The second section delves into a variety of observing-related topics. There is plenty of useful information on telescopes — including how to calculate magnification and field of view. Graun presents good tips on star hopping, and provides multicolor star charts that are both pleasing to the eye and work well at night with little light. He also includes detailed charts for the complicated areas of Sagittarius and the Virgo Cluster.

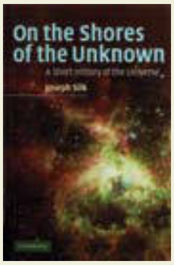
The heart of the book is devoted to the Messier catalog objects. Graun uses two pages for each object and includes both Messier's original description and Dryer's entry in the NGC catalog. Modern information on each object includes the object type, location, the best observing periods for both evening and morning hours, and descriptive notes using a 4-inch refractor at 48x (the telescope Graun used for this book).

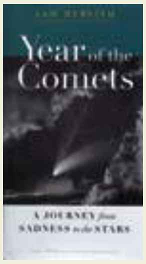
All images of the Messier objects are the same size and include both a scale (in arcminutes) and an orientation arrow to north. Lastly, each object is rated from easy to difficult in terms of location and observation under both dark and light-polluted skies.

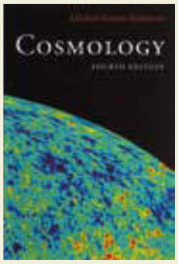
The layout of the book is user-friendly and organized. However, it does have a few minor errors. For example, M77 is a high-surface-brightness Type II Seyfert Galaxy. It does not have "low-surface-brightness" nor is it "similar to M74," as Graun writes.

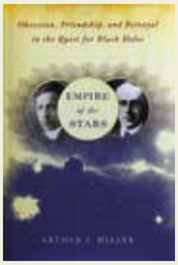
Also, even though it is a great instructional tool to have all images set to the same scale, it would be helpful to have larger image inserts for some of the smaller galaxies and planetary nebulae.

But these are minor issues. Overall, this book is an excellent reference for the beginner, and even the more seasoned observer. Graun's book is well conceived and would be a welcome addition to any amateur's library. — **RICHARD JAKIEL** *is an amateur astronomer in the Atlanta area.*









On the Shores of the Unknown

Joseph Silk, 240 pages, Cambridge University Press, 2005; hardcover, $35

Beginning with descriptions of orders of magnitude, Obers' paradox, and Doppler shift, Silk lays the foundation for a well-explained cosmology book. But this isn't a complicated textbook. Its reader-friendly text covers the formation of ordinary matter to the curvature of space, to black holes and galaxy formation. It's aimed at the general reader interested in cosmology.

Year of the Comets

Jan DeBlieu, 201 pages, Shoemaker & Hoard, 2005; hardcover, $23

Skywatching helps the author keep her perspective as her husband Jeff sinks into depression, in this personal memoir that features stars and constellations as fixed reference points and seasonally recurring friends. A clear, moonless night on Virginia's Eastern Shore brings an epiphany, and the arrival of comets Hyakutake and Hale-Bopp frames the story of Jeff's eventual recovery.

Cosmology

Michael Rowan-Robinson, 200 pages, Oxford University Press, 2004; paperback, $44.50

An introductory cosmology textbook aimed at undergraduates, this publication has some basic calculus and assignment problems. Rowan-Robinson has included, in this fourth edition of his text, recent findings up to May 2003. There is also what he considers the 20 controversies of modern cosmology. Read this, and then look back to the first edition, published in 1977, and you can see how many questions cosmologists have answered ... and how many remain.

Empire of the Stars

Arthur I. Miller, 364 pages, Houghton Mifflin, 2005; hardcover, $26

This is the story of the discovery of black holes and the scientists who were involved with the discovery. Their personal and professional lives — and the competitiveness in the world of astrophysics — show there's more to scientific brilliance than a mathematical proof.

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NEXT MONTH

Cosmic shooting gallery
Could nearby high-energy cosmic bursts explain why we haven't detected extraterrestrial life?

Diamond worlds
Scientists who study extrasolar planets have good reason to believe future searches may uncover planets made of almost pure carbon.

As far as Hubble can see
Astronomer Sangeeta Malhotra provides an insider's look at the Hubble Ultra Deep Field.

Set your sights on Mars
After a 2-year hiatus, the Red Planet is back! While not as big or bright as in 2003, this year's martian visit may be better for observers north of the equator. If you're interested in viewing Mars, don't miss this common-sense guide.

Shoot the Moon
Taking quality high-resolution lunar photos demands patience and ruthless determination. We give you some tips to help you capture the Moon.

Vixen Sphinx
This new telescope mount by Vixen comes with a full-color LCD controller. It's fun to use, but is the mount as impressive as the display?

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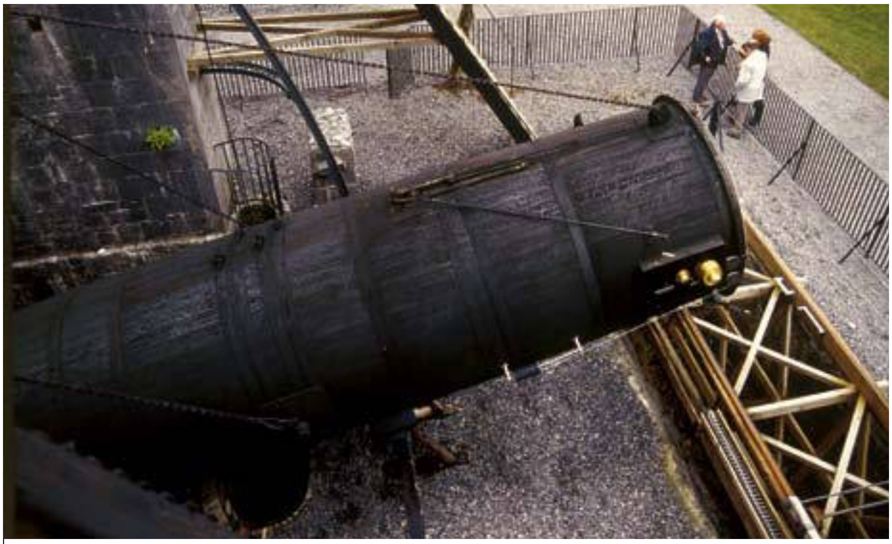
OCTOBER 7–9, 2005

Dooley's Hotel in Birr, Ireland, is home to the Whirlpool Star Party, the premier astronomical event for amateur astronomers in Ireland. Hosted by the Shannonside Astronomical Club, this is the 20th annual gathering. ☾ Why is this event named "Whirlpool"? In 1850, William Parson, third earl of Rosse, first detailed the spiral structure of M51, the Whirlpool Galaxy. The earl viewed this object with the "Leviathan of Parsonstown," the 72-inch scope still housed at Birr Castle. Although dismantled in 1914, the instrument has been restored and is a popular attraction during Birr tours.



ASTRONOMY: DAVID J. EICHER

THE LEVIATHAN OF PARSONSTOWN, completed in 1845, was the largest scope in the world until it was eclipsed by Mt. Wilson's 100-inch Hooker Telescope in 1917.

Featured speakers this year may include Michael McKay of the European Space Agency, astronomy author Wil Tirion, and Steven Beckwith, former director of the Space Science Institute.

For more information, visit www.geocities.com/shannonsideac.

SEPTEMBER 24

ScopeOut

Cincinnati Observatory, Cincinnati. Amateur astronomy guru John Dobson will be the keynote speaker. Fans of antique astronomy equipment will be spoiled — the landmark observatory is home to an 1843 Merz and Mahler refractor and 100-year-old Alvan Clark and Sons telescope. For more information, call 513.321.5186; web site, www.cincinnatiobservatory.org/scopeout.

SEPTEMBER 29–OCTOBER 2

Southern New Mexico Star Party

City of Rocks State Park, near Bayard, New Mexico. Hosted by the National Public Observatory, this event is held at a scenic state park with an elevation of 5,000 feet, ensuring dark skies. For more information, visit astronomy-national-public-observatory.org.

SEPTEMBER 30–OCTOBER 1

All-Arizona Star Party

Farnsworth Ranch, near Arizona City,

Arizona. The dominant regional flora is creosote bushes, so the horizon will be unobstructed. For more information, visit eastvalleyastronomy.org/aasp.htm.

SEPTEMBER 30–OCTOBER 1

Hidden Hollow Star Party

Warren Rupp Observatory, Mansfield, Ohio. The observatory is home to a 31-inch reflector. Sponsored by the Richland Astronomical Society, this star party will feature observing, workshops, and lectures. For more information, visit www.wro.org/hiddenhollow2005.htm.

SEPTEMBER 30–OCTOBER 1

White Sands Star Party

White Sands National Monument, near Alamogordo, New Mexico. Registered participants will enjoy special considerations that other park visitors lack, including speakers, camping privileges, and tours of nearby National Solar and Apache Point Observatories. For more information, visit www.zianet.com/wssp.

SEPTEMBER 30–OCTOBER 2

Great Lakes Star Gaze

River Valley RV Park, near Gladwin, Michigan. This central Michigan location offers the advantage of a dark sky without driving to a rural location in the northern areas of the state. For more information, visit www.boonhill.net/sunset.

OCTOBER 1

NOVAC Star Gaze

Crockett Park, Fauquier County, Virginia. Although the site is easily accessible from Washington, D.C., light pollution from the metro area won't spoil views of many deep-sky gems. For more information, visit www.novac.com.

OCTOBER 1–9

Okie-Tex Star Party

Camp Billy Joe, near Kenton, Oklahoma. Although this 8-day-long event offers vendors, door prizes, and workshops, the real draw is the dark-sky observing from this Texas panhandle region. For more information, visit www.okie-tex.com.

OCTOBER 7–9

Tennessee Star Party

Camp Nakanawa, Crossville, Tennessee. This site features some of the darkest skies in Tennessee. Proceeds from this star party are used for community-outreach activities. For more information, visit bsasnashville.com/tnsp.

OCTOBER 7–9

University of Arizona Beginning Adult Astronomy Camp

Mt. Lemmon Observatory, Coronado National Forest, Arizona. This camp is designed for adults who have little or no experience in astronomy. Not only could this be a camper's first peek through an eyepiece, but attendees will have the opportunity to use two 60-inch telescopes at Mt. Lemmon Observatory. For more information, e-mail Don at dmccarthy@as.arizona.edu; web site, www.astronomycamp.org.

OCTOBER 8

Urban Starfest

Sheep's Meadow, Central Park, New York. Yes, you can see stars from Manhattan. The Amateur Astronomers Association of New York will host this event and provide telescopes for viewing deep-sky objects. For more information, call 212.535.2922; web site, www.aaa.org.

OCTOBER 26–30

Deep South Regional Star Gaze

Camp Ruth Lee, Norwood, Louisiana. This new site will provide a darker sky than the previous location and has amenities conveniently located near the observing field. Unlike previous years, the Star Gaze will be able to accommodate RVs and campers. For more information, visit www.stargazing.net/dsrsg.

CONTACT INFORMATION

Please submit club announcements 4 months in advance to Coming Events, *Astronomy*, P. O. Box 1612, Waukesha, WI 53187, or jmcgovern@astronomy.com. Also use this e-mail address to submit your events for our online calendar.

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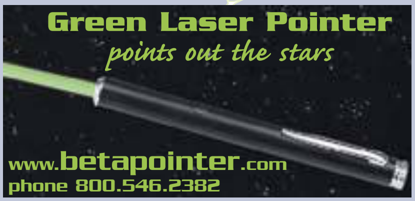
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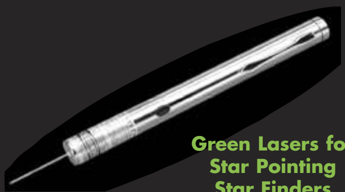

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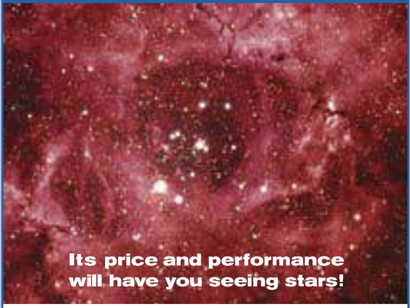

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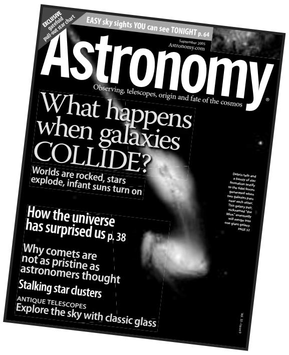
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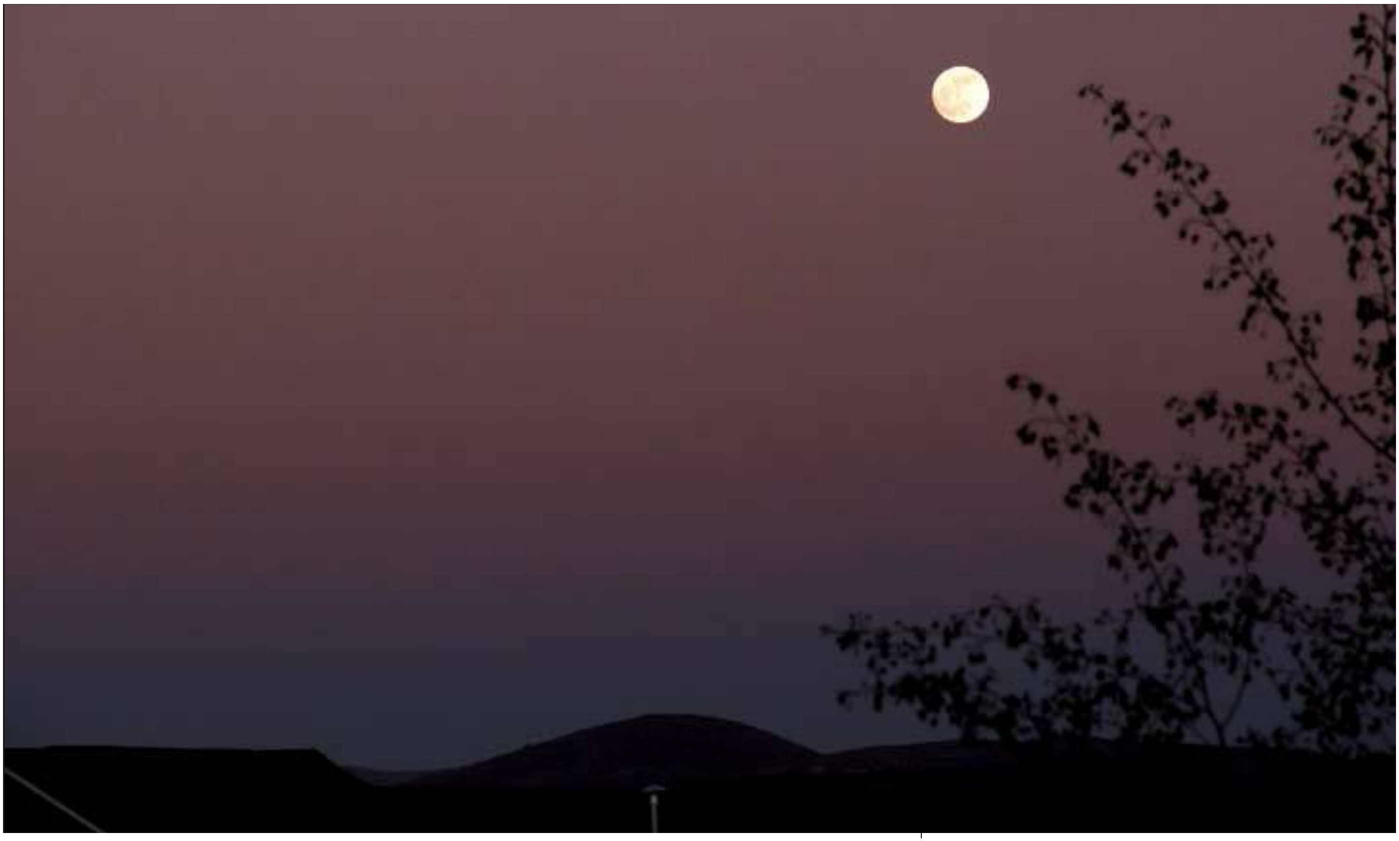
The belt of Venus /// Sun pillar /// Lunar crater Moretus /// The Eagle Nebula
Summer Milky Way /// Comet 9P/Tempel 1 /// Aurora /// All-sky view

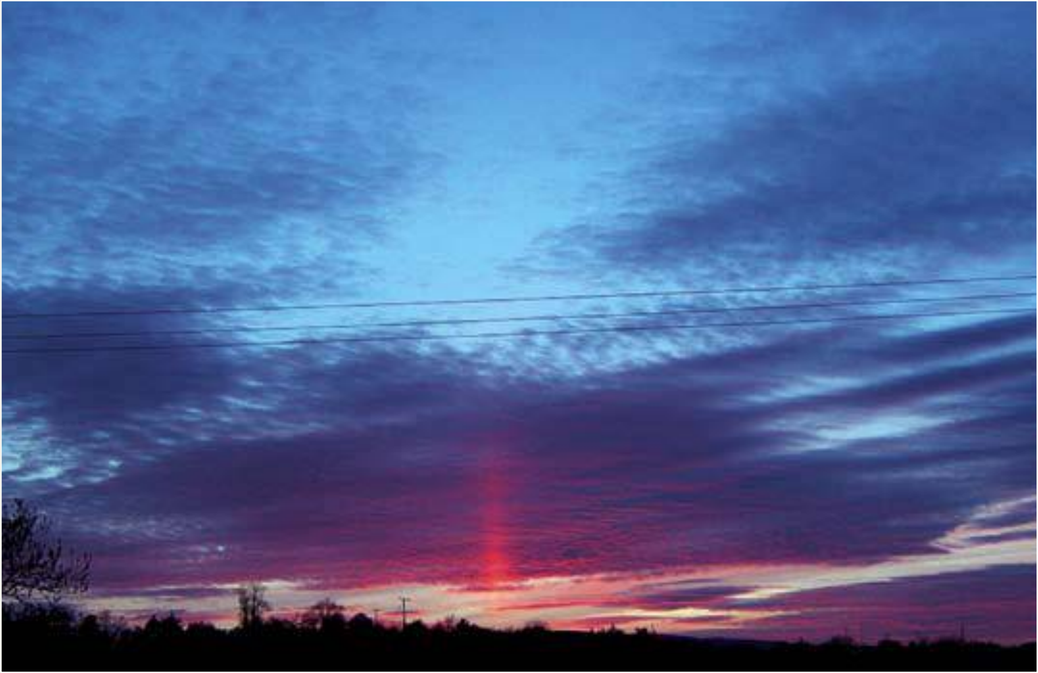


SKY COLORS

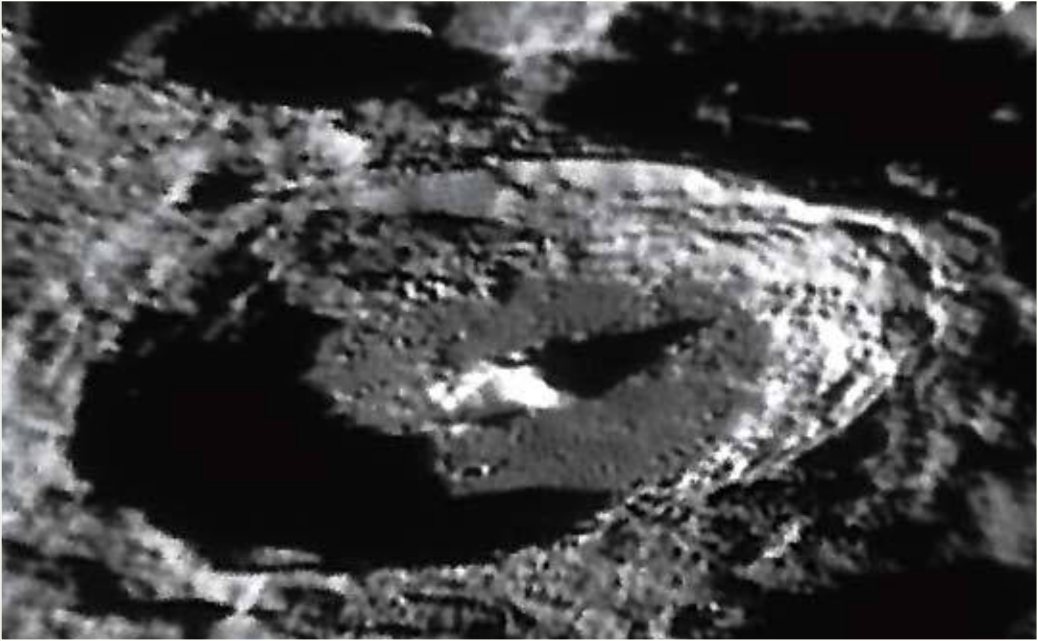
The Belt of Venus

In this image, the Full Moon is not the feature attraction. Instead, focus on the pink coloration of the sky just below the Moon. This is the belt of Venus and, oddly enough, it has nothing to do with the planet. At sunset, Venus sits in the west, and the belt lies low in the east. The name derives from the Roman goddess of beauty, Venus, who often wore a magic girdle (or, belt) to enhance her divine attributes. The dark band below the belt of Venus near the horizon is Earth's shadow, sometimes called the eclipsed sky. After sunset, you can watch Earth's shadow climb higher in the east as the Sun dips lower beneath the western horizon.

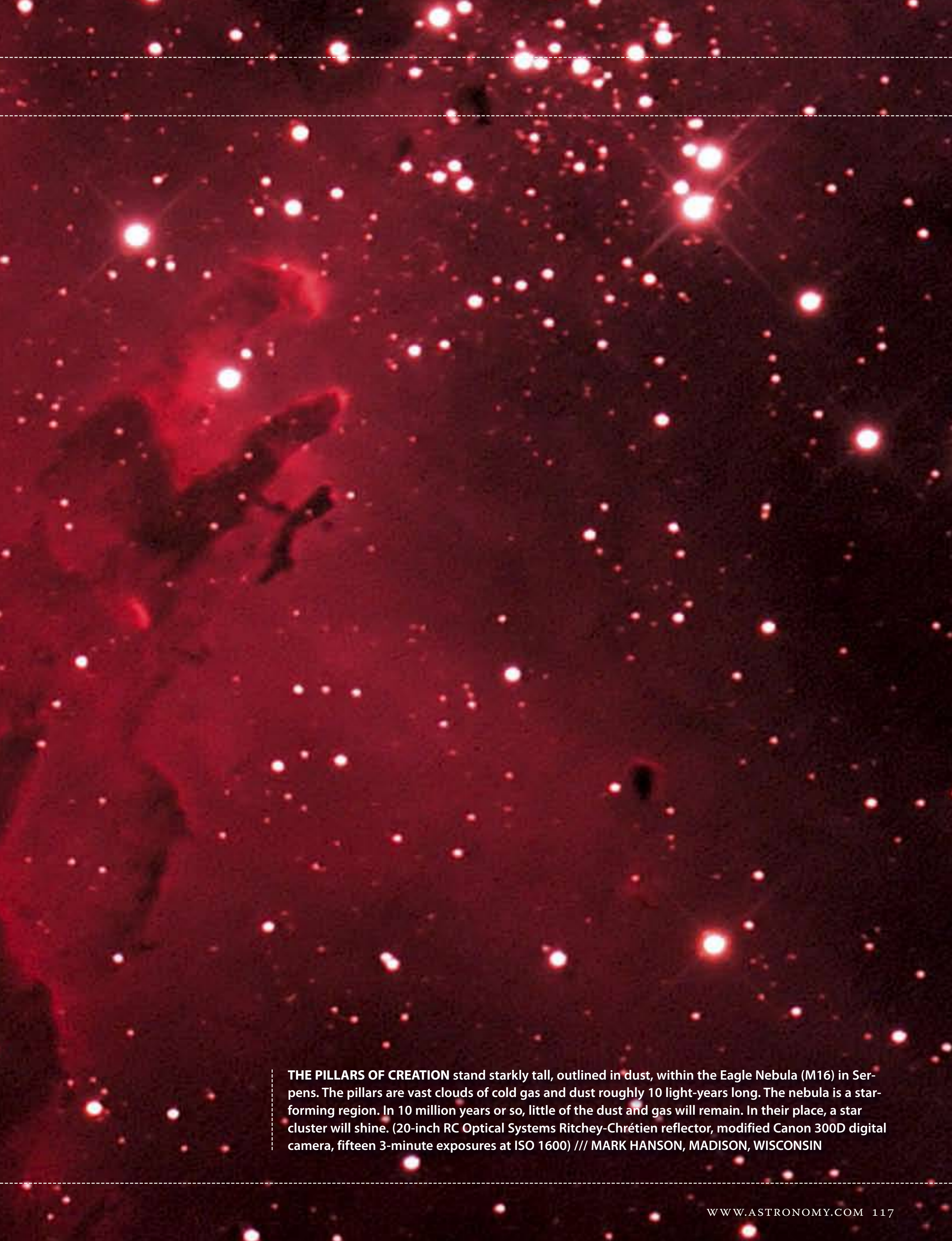
FULL MOON IN THE BELT OF VENUS **(Sony DSC-F717 digital camera, tripod-mounted, 1/125-second exposure, taken May 22, 2005) /// ANTHONY ARRIGO, PARK CITY, UTAH**



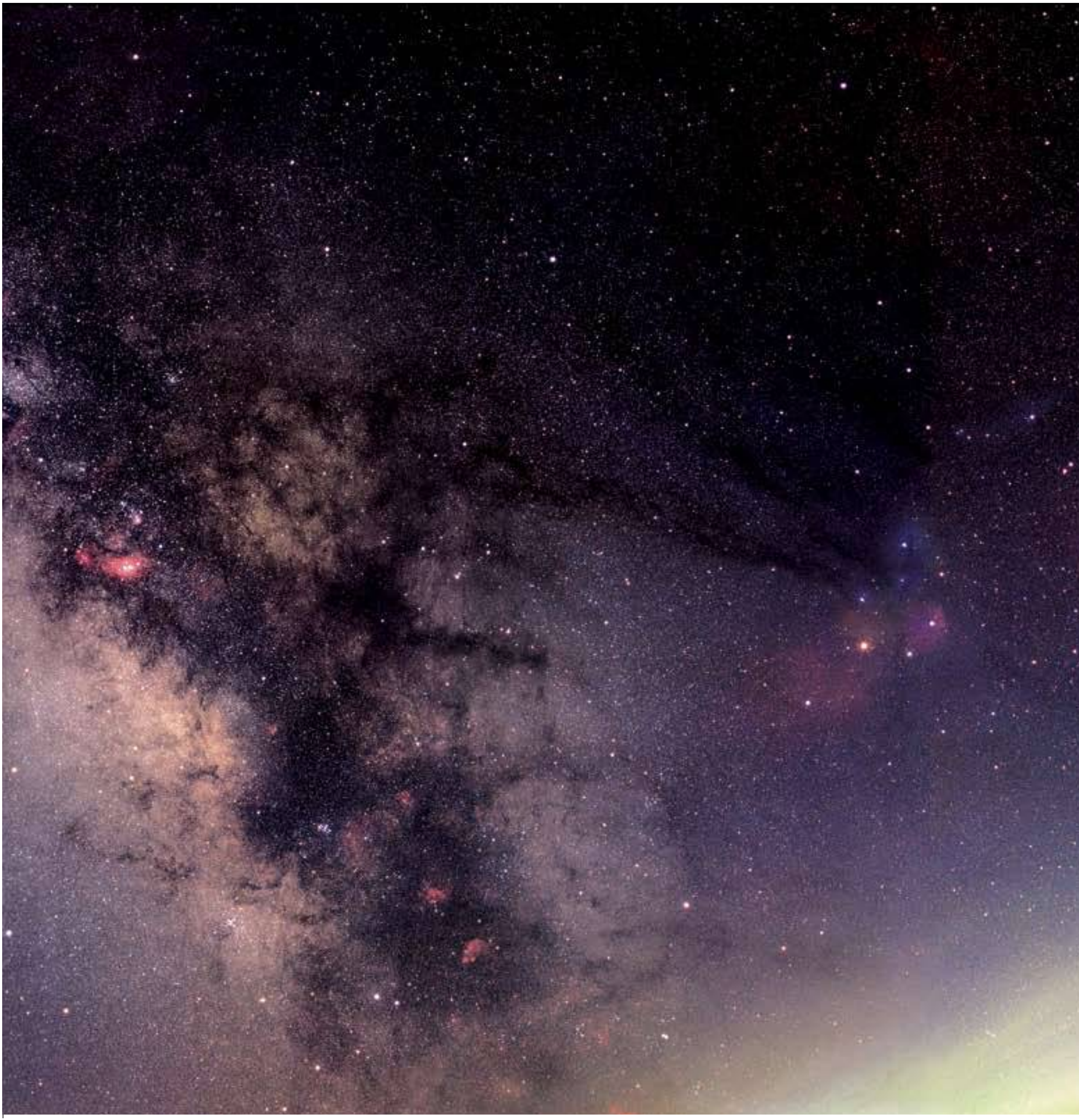
A COLUMN OF LIGHT reaches into the sky. Bright Sun pillars are uncommon sights. You can see them only around sunrise and sunset, and atmospheric conditions must be just right. The light column forms when tiny, six-sided ice crystals between your eyes and the horizon lie nearly flat, reflecting sunlight as they fall. The pillar takes on the color of the setting Sun. (Fujifilm Finepix E510 digital camera, hand-held, ISO 80, auto mode) /// MARTIN MC KENNA, MAGHERA, NORTHERN IRELAND



LUNAR CRATER MORETUS, a seldom-imaged feature of the Moon's southern polar region, resembles the more-famous crater Tycho. This 70-mile-wide crater has a prominent central peak and terraced walls nearly 13,000 feet high. The low Sun angle provides lots of shadow detail. (11-inch Celestron at f/40, 3x Tele Vue Barlow lens, ATK high-resolution monochrome CCD camera, best 150 out of 500 1/50-second exposures were chosen, taken March 19, 2005, between 20h07m UT and 20h09m UT) /// DAVID TYLER, FLACKWELL HEATH, ENGLAND

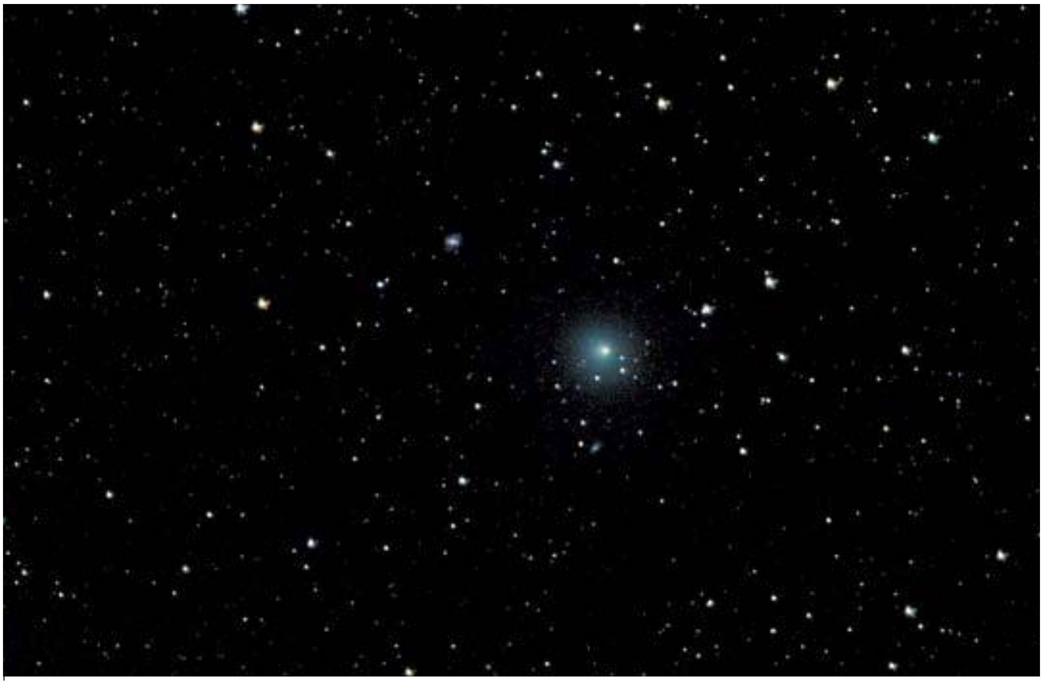


THE PILLARS OF CREATION stand starkly tall, outlined in dust, within the Eagle Nebula (M16) in Serpens. The pillars are vast clouds of cold gas and dust roughly 10 light-years long. The nebula is a star-forming region. In 10 million years or so, little of the dust and gas will remain. In their place, a star cluster will shine. (20-inch RC Optical Systems Ritchey-Chrétien reflector, modified Canon 300D digital camera, fifteen 3-minute exposures at ISO 1600) /// MARK HANSON, MADISON, WISCONSIN

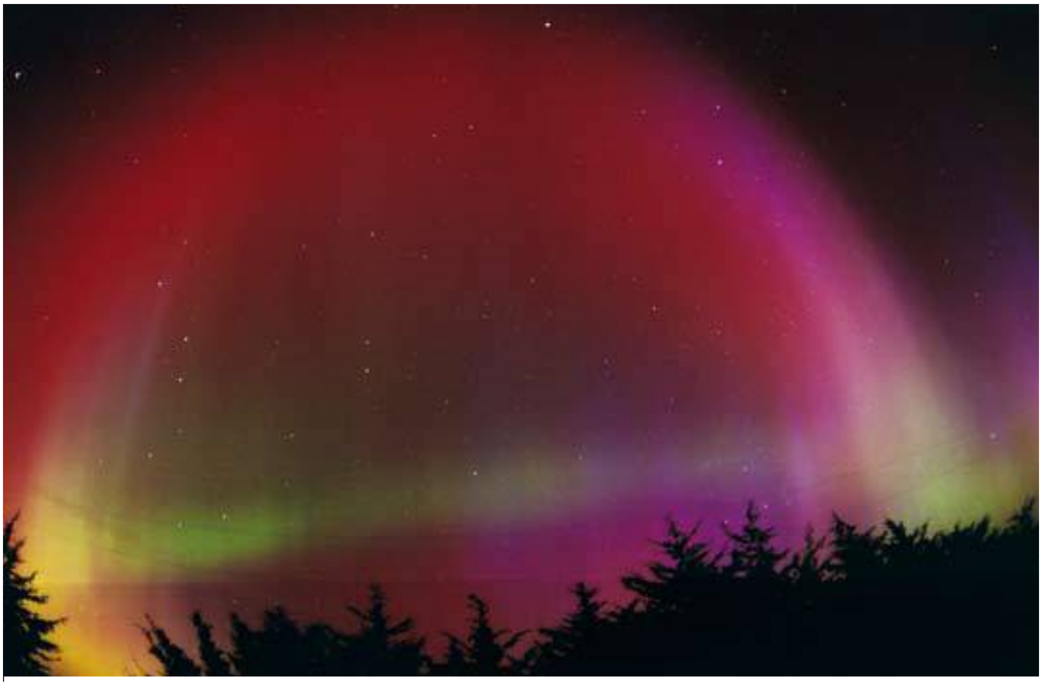


THE SUMMER MILKY WAY contains celestial objects worthy of any observer's attention. This image captures the season's three prominent constellations — Scorpius, Ophiuchus, and Sagittarius — that lie near the southern horizon for Northern Hemisphere observers. Bright nebulae and globular clusters highlight the area, but don't forget to turn your binoculars or wide-field telescopes toward the many dark nebulae here also. (Mamiya 6x7 film camera, 110mm lens at f/5.6, Kodak Ektachrome E200 Professional film, ISO 400, three-part mosaic: 30 minutes [left], 30 minutes [center], 20 minutes [right]) /// **DANILO PIVATO, ROME**

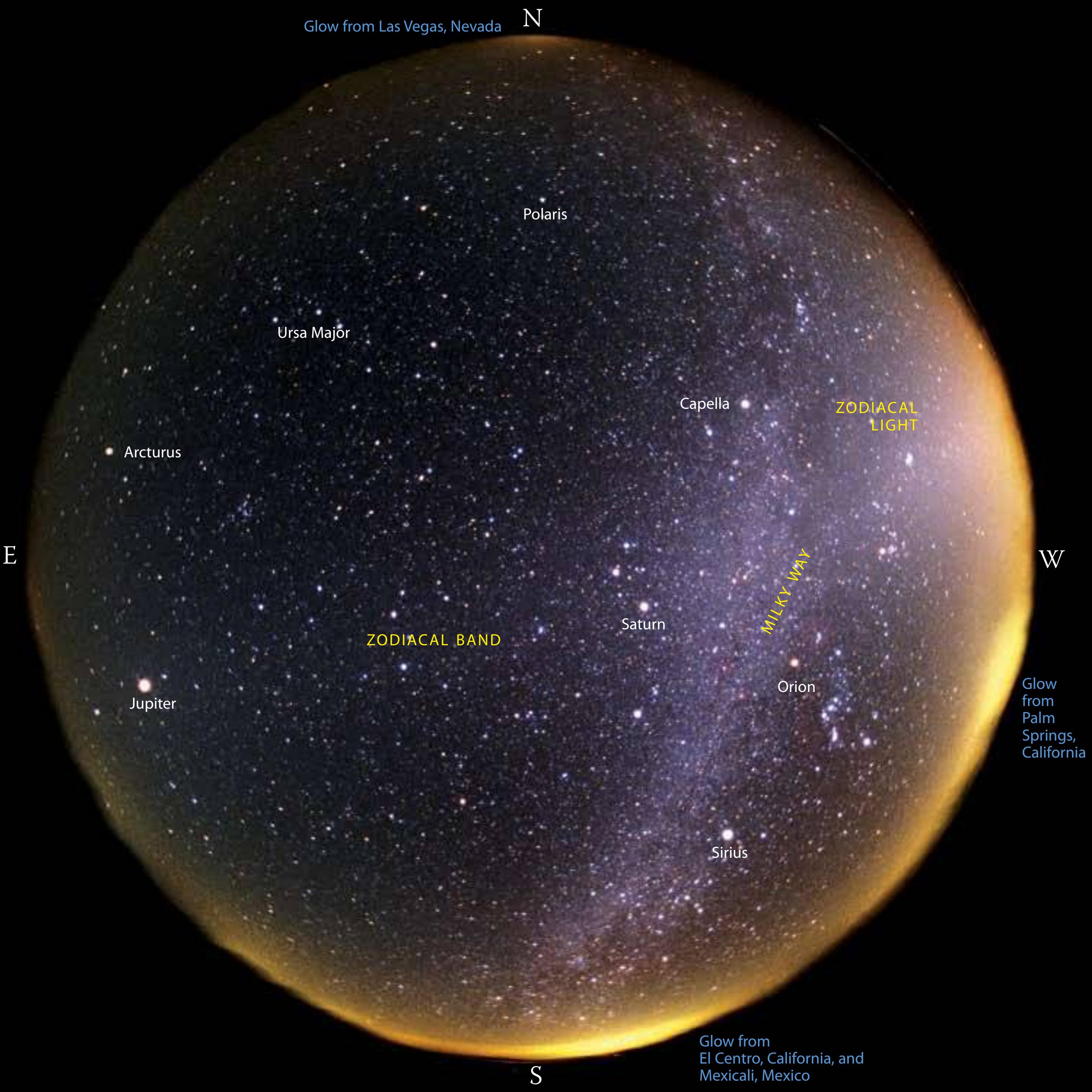
Send your photos to: *Astronomy* Reader gallery, P. O. Box 1612, Waukesha, WI 53187; e-mail to readergallery@astronomy.com.
Please include your full name, date and location of image, and complete photo data: telescope, camera, film, and exposure information.



BEFORE BEING BLASTED by the Deep Impact spacecraft, Comet 9P/Tempel 1 looked like a normal comet. This image shows the comet adrift in northern Virgo a little less than 2 months before being struck by an 800-pound copper impactor released by Deep Impact. (8-inch Schmidt camera, Starlight Xpress SXV-H9 CCD camera, LRGB image with exposures of 5, 3, 3, and 3 minutes, respectively, taken May 8, 2005, at 22h05m UT) /// **GERALD RHEMANN AND MICHAEL JÄGER, VIENNA, AUSTRIA**



THIS BRIGHT AURORAL DISPLAY is summed up best by the photographer: "The visible pale green curtain spanned from northwest to east along the horizon. The pillars shot up and formed a pointed arc meeting at the zenith. Red concentrations began to show in with the green, and the limits of the auroral display were met with shades of red." (Nikon film camera, Fujicolor 400 film, 40-second exposure, taken May 15, 2005, at 3:11 A.M. CDT) /// **BRENDA CULBERTSON, MAYETTA, KANSAS**


Glow from Las Vegas, Nevada
N
Polaris
Ursa Major
Capella
ZODIACAL LIGHT
Arcturus
E
W
MILKY WAY
Saturn
ZODIACAL BAND
Orion
Jupiter
Glow from Palm Springs, California
Sirius
Glow from El Centro, California, and Mexicali, Mexico
S

SEEING THE WHOLE SKY at once can be daunting until you locate some familiar identifiers. In this image, Jupiter (in Virgo) is the brightest object, followed by Sirius and Saturn (in Gemini). The winter Milky Way stretches north to south. Along with light pollution from three metropolitan areas, the cone-shape zodiacal light lies above the western horizon. Even the seldom-seen zodiacal band is visible as a faintly illuminated strip crossing from left to right. (Nikon F2A film camera, Nikkor 8mm Ai fish-eye lens at f/2.8, Fujichrome Provia 400F film pushed 1 f-stop, Astro-Physics 400GTO mount, 25-minute exposure; taken in the Palen-McCoy Wilderness area near Desert Center, California) /// CHRIS COOK AND JIM JANUSZ, EAST DENNIS, MASSACHUSETTS

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Meade DSIPro (L=10X4 min., R=6X4 min, G=6X4 min, B=2X4 min). Processed with Drizzle.

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Cosmic microwave background
z = 20
First stars
z = 6
z = 4
z = 2
z = 1
z = 0.5
z = 0.1
z = 0.01
SDSS quasars
SDSS galaxies
Redshift scale (z)
Subaru Deep Field galaxy at z = 6.578
Unreachable (z = 1.6876)
GRB 990123
QSO 0957 +561
Expanding universe begins accelerating (z = 0.7554)
QSO 0957 lens
3C 273
Sloan Great Wall
CfA Great Wall
Coma cluster
Great Attractor
Megaparsecs
M77
Antennae galaxies
M87
Sombrero Galaxy
M74
Whirlpool Galaxy
M101
M81
Pegasus dwarf galaxy
Leo A
GR 8
NGC 3109
IC 10
M33
Andromeda Galaxy
IC 5152
Aquarius dwarf galaxy
NGC 6822
Phoenix dwarf galaxy
Leo II
Leo I
Local Group
Fornax dwarf galaxy
Draco dwarf galaxy
Sextans dwarf galaxy
Carina dwarf galaxy
Large Magellanic Cloud
Small Magellanic Cloud
Sagittarius dwarf galaxy
Kiloparsecs
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Perseus arm
Scutum-Crux arm
Orion arm
M13
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Vanguard 1
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Ionosphere
Hubble Space Telescope
Earth's surface and crust
Mantle
Earth
Liquid outer core
Solid inner core

Astronomy magazine

Cosmic vista

/// BY J. RICHARD GOTT AND MARIO JURIĆ

This chart plots the known universe at a glance as seen from a spot on Earth's equator. Looking left to right, the chart is a 360° panorama that extends out into space, showing the entire sky. We plot the universe vertically along the chart on a scale that increases by 10 times every 1.46 inches (3.7 centimeters). Objects 10 times more distant appear at 1⁄10 their size, which lets us plot everything from Earth's interior to the universe's most distant galaxies on a single sheet. The chart shows objects positioned as they were August 12, 2003. We've selected a sample of objects within 2° of Earth's equatorial plane and included other famous objects beyond this slice.

Legend

Black hole	⬭ Nearby galaxies
□ Diffuse nebula	Pulsar
Planetary nebula	⊙ Pulsar with planets
Spacecraft	⊕ Globular cluster
Comet	✷ Named stars
■ Satellite	⊙ Stars with planets

The most distant thing we can observe is the cosmic microwave background, which is radiation left over from the Big Bang. Because the universe is expanding, light from distant objects appears redder by an amount that depends on how far away they are. Astronomers use the "redshift," which they abbreviate as z, of distant light to help them determine cosmic distance. Light from the creation of our universe has been redshifted so far it's no longer sensed as light, but as microwaves.

As we descend the chart from the microwave background, we emerge into a web of 126,594 Sloan Digital Sky Survey (SDSS) galaxies and quasars. The SDSS galaxies all occur within 2° of the celestial equator — Earth's equator projected into space. The obscuring dust of our own galaxy creates the central blank region, where no SDSS galaxies are shown. All 31 SDSS quasars with redshifts greater than 5 are also plotted.

The Sloan Great Wall of galaxies is the largest structure in the universe, spanning 1.37 billion light-years. For comparison, we've plotted density contours for the other Great Wall of galaxies, one discovered in the late 1980s by Margaret Geller and John Huchra at the Harvard-Smithsonian Center for Astrophysics (CfA). The CfA Great Wall is 0.758 billion light-years long — about half the Sloan Great Wall's size — but it appears 2.5 times larger here because it's 2.5 times closer to us.

In recent years, astronomers have learned something interesting happens at redshift 0.7554. This is where the universe transitions from a slowing expansion to an accelerating one. Because of this acceleration, photons (and spaceships) sent from Earth can never reach objects farther than $z = 1.6876$, so we've labeled the distance beyond as "Unreachable" on the chart.

Closer to home, we begin to see the familiar galaxies that make up our Local Group, the collection of galaxies that includes our Milky Way. The Large and Small Magellanic Clouds (LMC and SMC) are satellites of our own galaxy. The Sagittarius dwarf spheroidal galaxy is one, too, but it has begun to merge with the Milky Way.

The Milky Way's visible disk, distorted in our all-sky view, looms large. Then, we descend toward a single, special star — our Sun — residing in one of its spiral arms. The disk gradually blocks our view of the galaxy's center, which harbors a 2.6-million-solar-mass black hole. Well-known galactic objects appear, including M13 — one of 150 of our galaxy's globular clusters — as well as the Crab Nebula (M1) supernova remnant, the star-forming Eagle Nebula (M16), and the Ring Nebula (M57).

Between 1989 and 1993, the Hipparcos satellite measured the distance to thousands of stars in Earth's equatorial plane; we show them all here. Stars surrounded by circles harbor known planets. Familiar stars, including the brightest ones visible in our sky, also now appear. It's in this realm we encounter the first evidence that a star in our galaxy has developed life — radio waves launched by our own civilization have traveled out this far. Proxima Centauri, just 4.22 light-years from us, is the closest-known star to our Sun.

At last, we begin to enter the fringes of our own solar system. The Oort Cloud of comets extends from about 100,000 to 8,000 times the radius of Earth's orbit around the Sun. The gravity of passing stars and molecular clouds easily nudges Oort Cloud comets into orbits that will bring them close to the Sun. On the way, the planets — especially giant Jupiter — may alter their paths again. Such changes can either eject comets from the solar system or force them into much shorter orbits. Such a change happened to Comet Halley, the most famous comet of all and the first whose return appearance in our skies was predicted.

Only now do we see the first objects made by human hands — the most remote of Earth's spacecraft armada. Pioneer 10, launched in 1972, and Voyagers 1 and 2, launched in 1977, are headed out of the solar system on their way to the heliopause, where particles from the solar wind meet gases between the stars.

Next come Pluto, hundreds of Kuiper Belt objects like Quaoar, and the curious micro-world Sedna.

Now a flurry of small objects appears. Asteroids swarm on either side of Jupiter's orbit. These are the Trojan asteroids, which are trapped in the stable L4 and L5 Lagrangian points 60° ahead of and behind the giant planet. Thousands of main-belt asteroids crowd the plot where a slice along Earth's equator cuts the ecliptic plane and the density of asteroids is highest. The largest of the lot are Ceres, Vesta, and Pallas.

We're looking at the sky at a specific date — August 12, 2003, the last Full Moon before Mars' 2003 closest approach to Earth. This snapshot catches 10 small bodies, called near-Earth objects, drifting past our planet.

Above the Full Moon, orbiting the Sun at the stable L2 gravitational point behind Earth, is the Wilkinson Microwave Anisotropy Probe (WMAP), which measured minute variations in the cosmic microwave background. The Solar and Heliospheric Observatory (SOHO) orbits at the opposite L1 point — an appropriate station for this Sun-watching satellite.

We've plotted all 8,420 artificial satellites in orbit around Earth as of August 12, 2003, including the International Space Station and the Hubble Space Telescope. We've plotted the inner and outer Van Allen radiation belts — doughnut-shape regions of charged particles girdling Earth's equator — as well.

The ionosphere marks the practical outer extent of Earth's atmosphere. Below it lies the dry, tenuous stratosphere, where ozone screens harmful solar ultraviolet rays. The troposphere — home to all the weather we experience — merges into the thickness of the line representing Earth's surface and crust.

We've drawn Earth's circumference along its equator as a straight line scaled to be as thick as our planet's crust — topographic highs and lows on Earth's surface are too small to be seen. Below, an equatorial cross section of Earth's interior plots hot (bright) and cold (dark) plumes rising and falling, respectively, in the mantle. These features were measured by Princeton University seismologist Raffaella Montelli. Beneath the mantle is Earth's liquid outer core, under which lies our planet's solid inner core.

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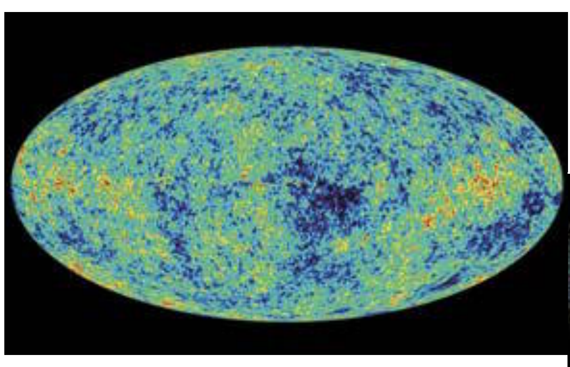
The universe in 4 steps

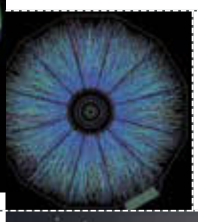
Ponder cosmic scale using Earth itself as the measuring stick. /// BY FRANCIS REDDY

We all like to think

THE FARTHEST THING WE CAN OBSERVE



CLOSER TO HOME,



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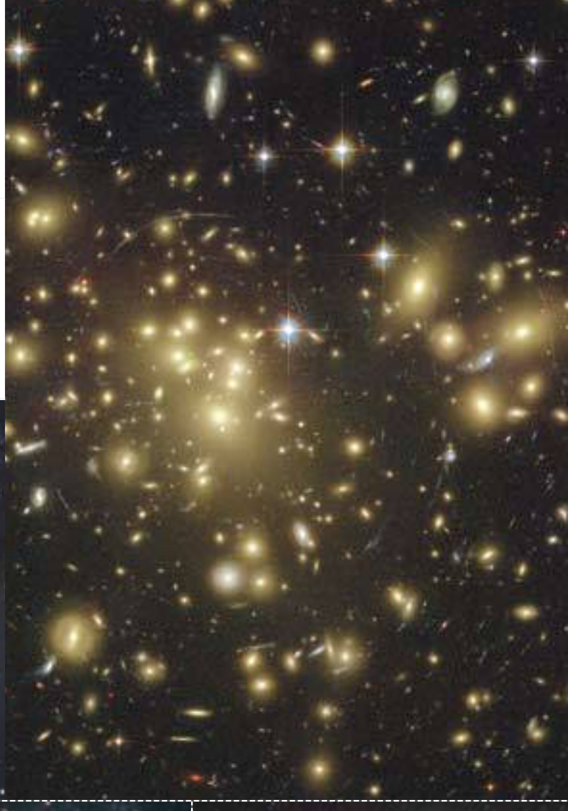
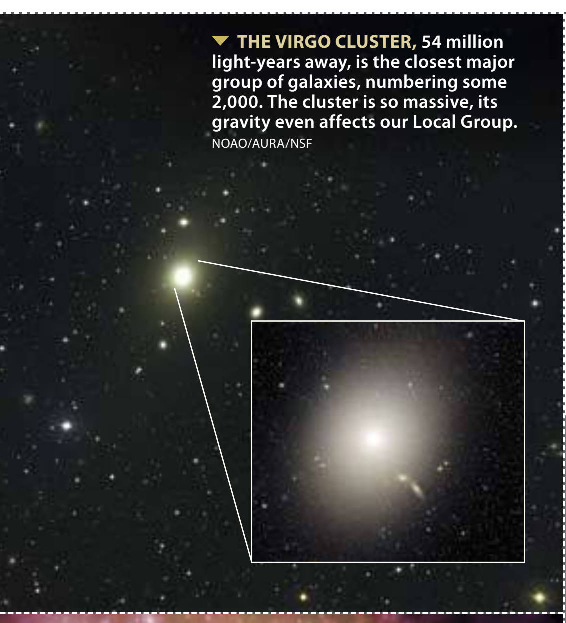




THE VIRGO CLUSTER, 54 million light-years away, is the closest major group of galaxies, numbering some 2,000. The cluster is so massive, its gravity even affects our Local Group. NOAO/AURA/NSF

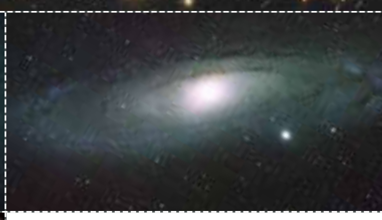
GALACTIC GOBBLER NGC 5128,

M87

4 Realm of the galaxies

From the nearest galaxies to the universe's edge — 1 million billion Earth radii to as far as we can see

THE LOCAL GROUP'S



THE NEAREST SPIRAL GALAXY

GRAVITY GATHERS

WE'VE LEFT THE MILKY WAY BEHIND,

THE EXPLODING STAR that created the Crab Nebula in Taurus was visible during daylight for 23 days, according to Chinese records from A.D. 1054. The star wreck will continue to expand for millennia. At its heart, forged in the blast, lies a neutron star just a few miles across. The Crab Nebula is 6,500 light-years away. NOAO/JPL/SSC/CALTECH/T. TEMIM ET AL.

THE GREAT HERCULES GLOBULAR

OUR SUN WILL CREATE

STAR FORMATION ON A MASSIVE SCALE takes place around Eta (η) Carinae, our galaxy's most massive and luminous star. Eta and more than 60 other massive suns — all remnants of a stellar birth pulse that ended 3 million years ago — energize the vast Eta Carina Nebula, which lies 7,500 light-years away. NOAO/AURA/NSF/N. SMITH

THE ORION NEBULA

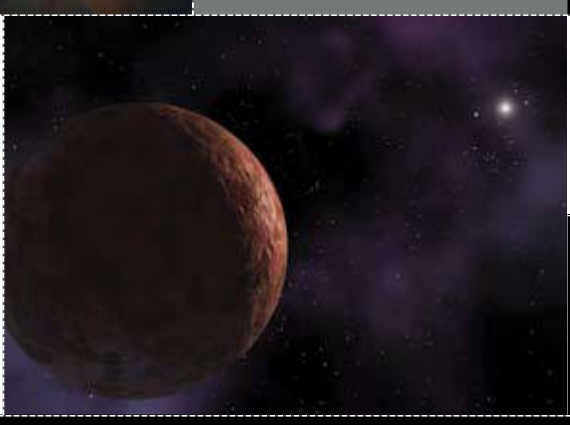
MEROPE SHINES

3 Entering the Milky Way

From the nearest stars to the nearest galaxies — 10 billion to 1 million billion Earth radii

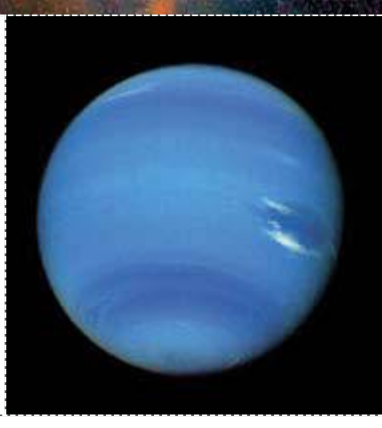
THE FIRST EXOPLANET

SEDNA



KING OF THE KUIPER BELT,

THE OTHER BLUE MARBLE,



Special supplement to *Astronomy* magazine
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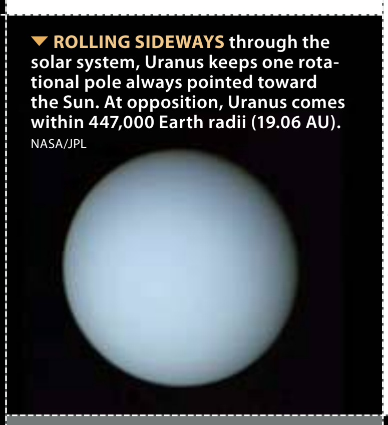
SATURN'S RINGED BEAUTY is never closer to us than 188,000 Earth radii (8.06 AU). Our best views of Saturn during the next few years will come from NASA's Cassini probe, now in orbit. NASA/JPL/SSI

ROLLING SIDEWAYS through the solar system, Uranus keeps one rotational pole always pointed toward the Sun. At opposition, Uranus comes within 447,000 Earth radii (19.06 AU). NASA/JPL

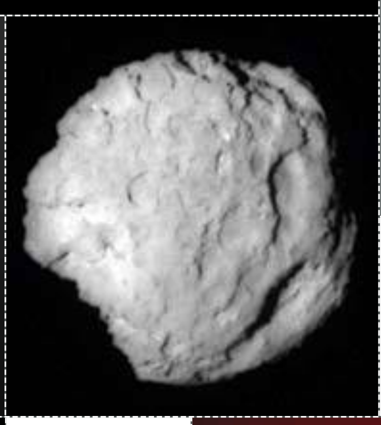


JUPITER,

2 Giant planets and ice balls

From Jupiter to the nearest stars — 100,000 to 10 billion Earth radii

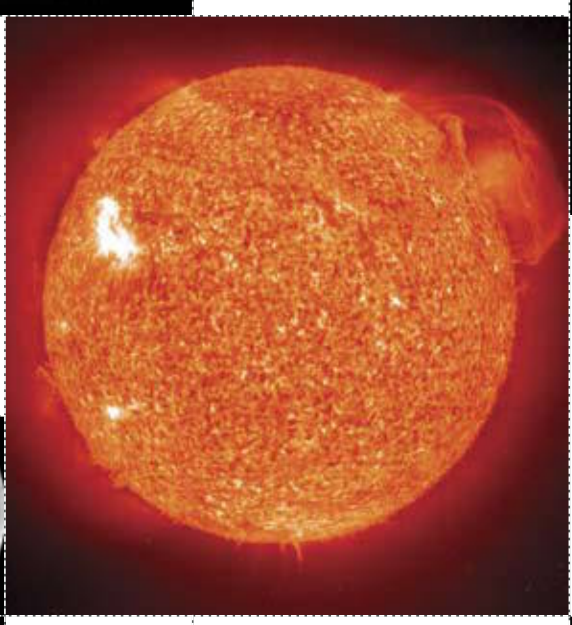
COMET HALLEY



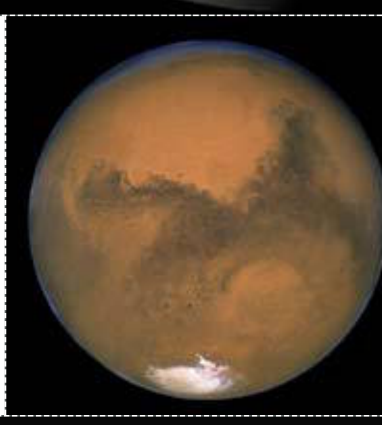
COMET WILD 2,

ASTEROID EROS

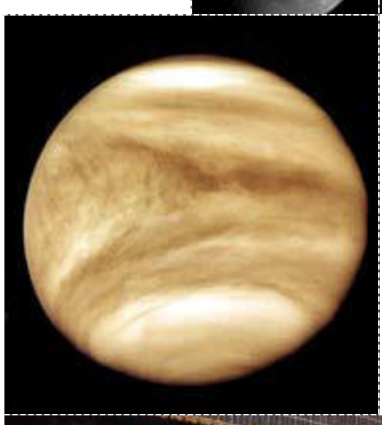
GASPRA,



THE RED PLANET



MERCURY,



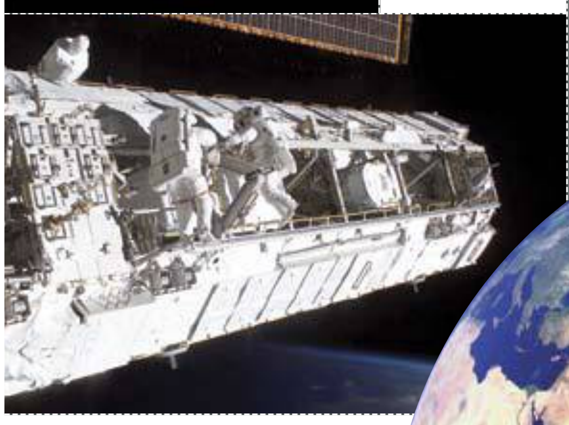
EARTH'S TROUBLED TWIN,

THE SOLAR SYSTEM'S

HUMANITY'S MOST DISTANT FOOTPRINTS were made on the Moon. In December 1972, Harrison Schmitt examined this large split boulder near Apollo 17's landing site at Taurus-Littrow. This was the last human Moon visit. When will we return? NASA

1 Earth and its neighbors

From Earth's surface to the asteroid belt — 1 to 100,000 Earth radii



MEN AT WORK,

EARTH'S COMPANION,

OUR HOME PLANET,

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